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SOIL CONDITIONS AFFECTING FERTILIZER EFFICIENCY[1]

A. V. Sokolov, *V. V. Dokuchayev Soil Institute, Academy of Sciences, USSR*

More than 100 years have passed since Justus Liebig, of whom Karl Marx wrote (6), applied himself to the task of replacing plant nutrients taken up by crops from the soil by the application of mineral fertilizers. Since that time ideas on the cycle of substances in agriculture have changed substantially; we endeavor to restore natural soil fertility by applying fertilizers and to obtain higher yields than could otherwise be reached on even the most fertile soils. Liebig was, however, the first (in the words of Pryanishnikov) to present the problem of "the conscious regulation of the exchange of substances between man and nature" (10), and, as a solution to this problem, he suggested organizing the manufacture of artificial mineral fertilizers. The study of the nutrient cycle and the part played by fertilizers in agriculture became the subject of much scientific research following Liebig's work.

Present-day knowledge of soil fertility and fertilizer application are based on: concepts of plant nutrient reserves in soils; conversion of these reserves into forms available to plants; nutrient requirements of plants; uptake of nutrients by crops from soil; entry and accumulation of nutrients in soil through fertilizer application; transformation of fertilizer in soils; biological fixation of nitrogen; and the effect of moisture, soil reaction, aeration, temperature and other soil and climatic conditions on plant nutrition.

Soil and climatic conditions governing the fertilizer efficiency vary throughout the USSR. Geographical laws governing fertilizer efficiency were elucidated in fundamental research of the Scientific Institute for Fertilizers (NIUIF) between 1926 and 1931. This institute compiled a summary of the results of all the experiments conducted in the USSR up to 1929, and organized planning of geographical experiments with fertilizers throughout the whole Union (3, 2).

The numerous studies of the All-Union Institute for Fertilizers, Agropedology and Agrotechnics (VIUAA) and of branch, regional and academic institutes, colleges, experimental stations and experimental fields made possible a considerable widening and deepening of our knowledge of fertilizer effects on the yield of various plants on the most diverse soils (15) in many regions of the Soviet Union.

Positive fertilizer effect on plant yields is explained either by nutrient deficiency in the soil or by elimination of undesirable soil properties, for instance soil acidity. Nitrogenous, phosphorus and potassium fertilizers are applied with the aim of improving plant nutrition; thus the knowledge of available nutrient contents in the soil—which vary in different soil types—is of great practical importance.

Figures 1 and 2 summarize mean results of the effect of fertilizers in the geographical network (NIUIF) experiments and the data on total nitrogen and phosphorus contents in the soils according to the work of Bolotina (1) and Kheyfets (21). The experiments were carried out with moderate fertilizer rates of 45 to 60 kg./ha. each of N, P_2O_5 and K_2O and with high rates of 120 kg./ha. each of N, P_2O_5 and K_2O.

The effect of 45 to 60 kg. of P_2O_5 on all soils was almost the same; gray forest soils and thick chernozems showed slightly smaller yield increases. In experiments with high fertilizer rates (Fig. 2) these soil characteristics are more sharply expressed, and a smaller effect of phosphates on forest soils and on ordinary chernozems is observed. The effect of phosphorus fertilizers is not in direct relation to total phosphate contents in soils. Degraded and leached chernozems are richer in total phosphorus than gray forest soils, but phosphate has more effect on these soils than on gray forest soils.

The effect of nitrogen decreases with moderate rates of fertilizer, starting with thick chernozems; with high rates it decreases starting with ordinary cherozems (Fig. 1). The increase of total nitrogen and humus contents from podzolic soils to chernozems is many times greater than the decrease in the efficiency of nitrogen fertilizers. In spite of very high humus contents, degraded, leached and thick chernozems responded to fertilizer application as much as sod-podzolic clay loams low in humus content. Consequently, even the most general laws governing the effect of fertilizers do showed a great effect on yields of spring cereals, autumn cereals and root crops; spring wheat yields increasing almost three times; winter wheat $1\frac{1}{2}$ to 2 times; potatoes more than 3 times. At the same time these data indicate a large reserve of available nutrients in soils of these regions, which makes it possible to obtain such results from irrigation. In Soil Institute experiments in the irrigated area of Rostov region, increases from fertilizer application were several times lower than those from irrigation. Nutrient uptake from non-fertilized soils increased greatly as a result of irrigation. It was found that irrigation increased the uptake of nitrogen by 46 to 113 kg./ha., of phosphorus by 12 to 38 kg./ha. P_2O_5 and of potassium by 61 to 110 kg./ha. K_2O. These data indicate the great soil fertility of the Rostov region irrigated area and show that irrigation makes possible intensive utilization of enormous reserves of soil nutrients.

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[1] Given at the First Congress of USSR Soil Scientists, May 12–18, 1958.

On soils of the Southeast fertilizer efficiency (23) changes with irrigation depending on soil group. On chestnut soils poorer in humus and nitrogen, and particularly on light chestnut soils, nitrogenous fertilizers have a greater effect, phosphorus fertilizers less, and potassium fertilizers very little. On ordinary and southern chernozems richer in humus and nitrogen, phosphorus and nitrogenous fertilizers sometimes have more effect, depending on weather conditions.

Thus, on soils of the Southeast, high fertilizer efficiency is recorded with irrigation; but irrigation itself shows a still higher effect. Even in the experiments in which the effect of fertilizers was very high, the yield of irrigated spring wheat without fertilizers was 22 to 31 centner/ha.,—large amounts of nutrients were utilized (20).

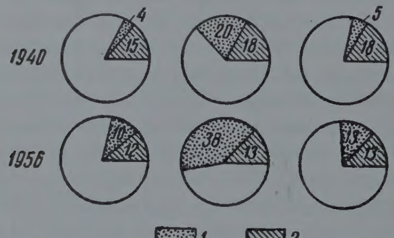

FIG. 3.—Part played by mineral fertilizers and farmyard manure in restoration of nitrogen, phosphorus and potassium removed from the soil, in % of removal. 1—Mineral fertilizers; 2—farmyard manure.

Soils of the Trans-Volga region, although poorer than chernozems of the Rostov region, have adequate nutrient contents which can be mobilized by irrigation. Irrigation, however, is an expensive means of mobilizing nutrients; for this reason its application on soils of the Trans-Volga region should be accompanied by fertilizer application, as only high yields of grain crops can justify the expense of irrigation (23).

Available nutrient content in the soil depends on: total contents and their conversionin to available forms, removal of these substances by crops, their application with fertilizers, and on their intake into the soil from the atmosphere.

The simplest index of the part played by fertilizers in the cycle of substances in agriculture is the relationship between the amount of nutrients applied to the soil with fertilizers and the removal of these elements by crops. From the works of Kochetkov (5), Pryanishnikov (11, 12) and published statistical data it is possible to calculate approximately which part of the total amount of nutrients removed by crops consists of nutrients applied in the form of fertilizers (Fig. 3). Nutrients applied with fertilizers now amount to $\frac{1}{5}$ to $\frac{1}{4}$ for nitrogen, $\frac{1}{2}$ to $\frac{2}{3}$ for phosphorus, and for potassium $\frac{1}{4}$ to $\frac{1}{3}$ of the total amount of nutrients removed from the soil by crops. These calculations indicate the great part played by fertilizers in agricultural production; but, they do not give an idea of the true utilization of fertilizer nutrients by plants, and are only a general average for the country as a whole.

The distribution of fertilizers between various regions of the USSR is very unequal (17). The small cultivated area in central Asia receives almost 100 times as much fertilizer per hectare as the cultivated area in the huge territory of western Siberia, White Russia and the Baltic countries, which in turn receives 3 times as much fertilizer per hectare as the center of the non-chernozem belt of the RSFSR. Cotton receives almost 100 times as much fertilizer per hectare as cereal crops. Sugar beet receives 7 times as much fertilizer per hectare as potatoes. If we consider that in industrial crop rotations only a certain part of the fertilizer is allotted to grain crops, which also benefit from the residual effect of fertilizers applied to industrial crops, we may conclude that only 10 to 12% of the area under grain crops at the present time is substantially affected by mineral fertilizers.

In some regions yields are obtained mainly from soil nutrients, and in others from fertilizers as a result of unequal distribution of fertilizers among various regions. Cotton and sugar beet plantations are fully provided with nitrogen from nitrogenous fertilizers, and receive twice as much phosphorus as is removed by crops. To date potassium fertilizers are not applied to cotton, and sugar beet receives potassium at a rate equivalent to its removal by the crop. Nutritional conditions of these crops are the same as in countries where mineral fertilizers are intensively applied.

In regions of intensive application of phosphate fertilizers a gradual "phosphate saturation" of soils takes place when crops do not respond to phosphorus fertilizers. At the present time "phosphate-saturation" of soils is found in regions where a slight phosphate retrogradation takes place, for example on sierozems, and on krasnozems, which are characterized by exceptionally strong phosphate fixation (19).

The task of agricultural chemistry includes examination of the problems of utilization of soil– and fertilizer–nutrients and utilization of other sources of plant nutrition, especially biological nitrogen fixation by leguminous plants. Hellriegel discovered nitrogen fixation in nodules of leguminous plants, but there are no precise data as to how much nitrogen is fixed by leguminosae in the ield.

Some time ago Pryanihnsikov (12) planned that areas under leguminous grass mixtures should be ncreased 2½ times and their yields twice. But during the 2 years from 1954 to 1956, the areas under clover decreased by 22%, under alfalfa by 0%; yields of hay, as before, are extremely low. The role of biologically fixed nitrogen in agriculure is not increasing but decreasing, and linked with this is the increasing need for nitrogen and potassium in mineral fertilizers. The gradual mergence of the need for potassium on chernozem soils occurred comparatively recently. Sugar beet and other root crops rapidly deplete the eserves of this element in the soil.

At Mironovska Experimental Station, on very ich, fertile coarse clay loam chernozem, a long-erm experiment with the application of mineral ertilizers and farmyard manure was laid down in he rotation (including garden beet). After applying only nitrogen and phosphorus fertilizers for en years a gradual decline in yields began. Poassium was then applied, and yields with NPK immediately increased by 81 to 93 centner of roots, while with NP they were no higher than on the control plots. The need for potassium gradually became evident on other soils too—on sod-podzolic sandy loams at Solikamsk Experimental Station and at Lyuberets Experimental Field. Not long ago potassium exhaustion was also observed on sierozem soils.

In cultivating rich chernozem soils the plants, need for phosphorus becomes apparent, and by methods of soil management, particularly by fallow cultivation, it is possible to mobilize considerable amounts of available nitrogen owing to the nitrification of soil humus (7). Therefore, as long as we have no sufficient amount of nitrogen for fertilizing grain crops, our attitude should be cautious towards the replacement of bare fallows by cultivated fallows with non-leguminous plants. Newly reclaimed soils are usually utilized for grain crops (wheat, rye, barley), which remove fewer nutrients than root crops (maize, mangolds, potatoes). Therefore with adherence to cultivation rules on virgin and long-fallowed chernozem soils it is possible over a number of years to obtain fairly high grain crop yields, first without fertilizers and afterwards by supplying them with phosphorus. Soil exhaustion takes place gradually; yields of plants being provided with the minimum consumption of soil nutrients. Thus the normal utilization of natural resources is made up for by the increasing fertilizer application at the right time. With correct soil cultivation, depletion of any element leads to the application of the deficient element in the form of fertilizers, not to the abandonment of fields to fallow. In earlier times when this was not known or when fertilizers could not be applied, the fallow system was resorted to and exhausted or weed-infested soils were abandoned for a number of years to restore soil fertility.

What are the natural resources for the restoration of soil fertility? For phosphorus and potassium they consist principally of the processes of hydrolysis of soil minerals and of gradual accumulation in the soil of available forms of phosphorus and potassium; for nitrogen they involve its intake with precipitation and in biological and non-biological nitrogen fixation. On non-cultivated fallow or on virgin land plants are not harvested, and there a gradual accumulation of nutrients in the form of humus takes place, which is subsequently mineralized when soil is brought back into cultivation. Thus soil fertility is restored in the fallow, and after a long time it is possible on comparatively rich soils to obtain moderate yields of grain crops without fertilizer application, as is shown by long-term experiments at the Rothamsted and Poltava Experiment Stations. But without fertilizer application high yields of all crops are obtainable only through increased mineralization of soil humus and by utilization of mineral reserves of available substances. Today, as in Liebig's time, the intensification of agriculture inevitably leads to increased fertilizer requirements. Means for the protection of natural soil fertility (erosion control), the protection of soils from exploitation, and the organization of the correct economic mobilization of natural resources and of the processes of natural restoration of soil fertility are of great importance in the national economy. All methods of agriculture—rotation, selection of varieties, soil cultivation, and subsequent care of plants—should be regarded as specific methods of utilizing soil nutrients and fertilizers. Agricultural chemistry is required where fertilizers are and are not applied. Without an understanding of the chemical processes determining the plant nutrition through soil nutrients and fertilizers, there is usually neither scientific agronomy nor scientifically sound agriculture.

At present the planning of production and application of fertilizers should consider two points: increasing fertilizer requirements in non-fertilized or inadequately fertilized regions, and the increase in residual effect of fertilizers ("phosphate-saturation" of soils) in regions of intensive fertilizer application. Until comparatively recently determination of the content of mobile available forms of nitrogen, phosphorus, potassium and other elements in the soil was regarded as almost hopeless. Now, the dependence of fertilizer effect on the content in the soil of chemically determined mobile forms of nutrient compounds is regarded as obvious. The question is—how to use them more precisely and cheaply.

To date fertilizer application has usually been carried out blindly without preliminary soil analysis, and without considering soil and plant characteristics. The services rendered by agricultural chemistry to agriculture are still insufficiently organized. Fertilizer is often applied by hand, without the necessary mechanization. The most effective methods of fertilizer placement are not employed.

Today in the USSR it is necessary more than ever to solve the problem of the conscious regulation of the exchange of substances between man and nature; the problem of the part played by soil and fertilizers in the cycle of substances in agriculture. This problem is solved differently for different regions of the USSR. Agricultural chemists, agronomists, and soil scientists throughout the Union should participate in its solution. This is the immediate chief task of agricultural chemistry, and should be discharged in order to plan production and fertilizer application more rationally, and to secure a high standard of supply of agricultural products to the population and to industry in the years to come. The second task, not less important, is to achieve a system in fertilizer application to eliminate waste, unprofitable application methods and application without preliminary analysis.

The emergence of agricultural chemistry resulted in the foundation of the chemical fertilizer industry; agricultural research then proved the necessity of the widespread application of chemistry to agriculture. Collective effort will solve the great tasks which confront us.

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PROBLEMS IN THE QUALITATIVE EVALUATION OF SOIL OF THE USSR

S. S. Sobelev and M. N. Malyshkin, *V. V. Dokuchayev Soil Institute, Academy of Sciences USSR*

INTEREST in soil quality in Russia goes far back into history. In the annals of the fifteenth, sixteenth, and the beginning of the seventeenth centuries we find descriptions and precise accounts of plowlands and lands suitable for cultivation which distinguish three and even four soil categories.

A new stage in the study of soil qualities began with the cadastral surveys of the Ministry of State Lands (1838–1867) for the leveling of state peasants' taxes, as a result of which a standard soil evaluation scale for Russia was compiled. This was the "Standard Classification of Tillable Lands by yields of Rye" which was appended to the Instruction of 1859. This site quality scale for soil is of interest even at present. The thirty-year cadastral work covered sixteen guberniyas. After the reform of 1861 soil evaluation work was taken over by the zemstvos. Their work, especially that of V. V. Dokuchayev (1, 2), and N. M. Sibirtsev (6), who evaluated the soils of the Nizhnegorodskaya and Poltavskaya Guberniyas, and that of their pupils and successors, formed the next stage in soil evaluation and land capability.

V. V. Dokuchayev made soil itself the basis of land evaluation and divided the work into two categories: the natural-historic, performed by soil-scientists, and the agricultural-economic, performed by economists with the cooperation of local experts and the participation of soil scientists in the precisely defined "natural soil areas."

Dokuchayev especially emphasized the first, i.e. the natural-historic part of evaluation work, pointing out that it is incorrect to evaluate land according to yield only, "inasmuch as land into which knowledge and labor have been put will be more productive than land whose owner takes but little care of it. A higher evaluation of productive land would in this case amount to a tax on the intelligence of the owner." (2, p. 247). P. A. Kostychev also wrote that the evaluation of soil merits according to yields and without considering the soil properties would lead to "the payment of heavy taxes on efficient farms. Tax excesses would thus seem to be a duty on propert improvement which, obviously, would retar agricultural progress." (3, p. 199).

Dokuchayev made differential rent I (usin modern terminology) the basis for qualitative soi grouping and land evaluation for tax leveling, a the same time discounting and isolating differential rent II. When, under like cultivation conditions in Nizhnegorodskaya Guberniya, this sit quality scale was used, a practically identica evaluation rating and comparative crop yield were obtained.

In 1955, by order of the Ministry of Agricultur of the USSR, work was begun on soil site qualit in the V. V. Dokuchayev Soil Institute, Academ of Sciences, USSR and a site quality scale of th natural-economic districts of the USSR was compiled. The average grain yield of the USSR a two different agrotechnical levels—the collectiv farms and the state experimental plots—wa taken as a basis. The same type of work, but o a larger scale and in accordance with the method of the V. V. Dokuchayev Soil Institute, was performed by workers of the USSR Ministry of Agriculture under the supervision of M. L. Terent'ev. (Tables 1 and 2).

This work showed that at similar agrotechnica levels yields depend primarily on soil-climati conditions, e.g. if the average grain yield is designated by 1.0 (USSR), the chernozems of th Krasnodar Region or the Vinnitskaya Region wil have a rating of 1.5, while the chernozems of th central chernozem region will be 1.0, the chestnu soils of the Western Kazakhstan Region will b 0.3, i.e. the productivity of 100 ha. in the Krasnodar Region or the Vinnitskaya Region is greate by five times than the productivity of 100 ha. i the Western Kazakhstan Region.

Using data from the Ministry of Agriculture o the USSR, S. S. Sobelev compiled a site qualit scale for soil-climatic conditions in the USSR. Th average grain yield of the USSR (Table 3) wa designated at 100 ratings. In spite of the grea difference in yields at different agrotechnica

TABLE 1

Comparative yields of grain crops by zones and republics. The average yield in the country as a total is rated 1.0 (data furnished by USSR Ministry of Agriculture)

Areas	Yields at experimental plots, (averages for 5 years, 1950–1954)	Yields in peasants' farms (average for 15 years, 1901–1915)	Yields on collective farms	
			1933–1937	1950–1953
Country's total	1.0	1.0	1.0	1.0
Northern regions	1.0	1.1	1.1	0.8
Northwestern regions	1.0	0.9	1.0	0.8
Non-chernozem center	1.0	1.0	1.0	0.8
Chernozem center	1.0	1.1	1.0	0.9
Volga region	0.7	0.8	0.7	0.8
Northern Caucasus	1.2	—	1.1	1.3
The Urals	0.9	1.0	0.9	0.9
Western Siberia	0.8	0.9	1.1	0.9
Eastern Siberia	0.9	1.0	1.1	1.1
Far East	0.8	—	0.9	0.9
Middle Asia	0.8	—	0.9	—
Kazakh SSR	0.7	0.7	0.7	0.8
Trans-Caucasus areas	1.1	—	1.1	1.0
Ukraine	1.2	1.3	1.1	1.4
Moldavia	1.1	1.3	—	1.4
Belorussia	0.9	0.9	0.9	0.7
Lithuania	1.2	1.1	—	0.9
Latvia	1.4	1.3	—	1.1
Esthonia	1.3	1.4	—	1.0
Karelian ASSR	0.9	1.0	—	0.8

levels, (higher by twice in the experimental plots than in collective farms), the yield ratio according to zones and provinces remains practically unchanged. The yields of the chernozems in the chernozem region at the pre-revolutionary peasant agrotechnical level, the collective farm level and the experimental plot level agree essentially with the average yield of the USSR at the mentioned three levels. I.e. differential rent II is closely related to differential rent I as far as fertility is concerned.

The breakdown of differential rents I and II in areas using fertilizers, e.g. in the non-chernozem belt and the forest steppe, presents a difficult problem in methods. In the non-chernozem belt the extensive use of fertilizers and highly developed agricultural methods which conform to local conditions may not only increase yields, but may considerably span the difference in the natural potential soil fertility in different zones and provinces.

An examination of the yield data and the site quality ratings in Tables 1, 2, and 3 may raise the question as to whether or not the soils in the various natural-economic districts of the USSR, having the same site quality ratings, are of equal value. For example in the northern regions with predominating podzols, in the regions of the non-chernozem center where sod podzols predominate, and in the chernozem center with its predominating chernozems, we find the grain yields to be practically identical and it would consequently seem that the site quality ratings would be the same, i.e. 1.0. Although having the same average perennial grain yield, the soils of these three natural-economic regions cannot be evaluated identically.

Data on the production cost of grain on collective farms, calculated by the USSR Ministry of Agriculture (5, p. 354), show very real differences in grain production costs in the foregoing natural-economic regions. If the average cost of producing grain in the collective farms throughout the USSR is taken at 100%, the cost in the North is 276, in the non-chernozem center—195, and in the chernozem center—98, i.e. 2.8 times less than in the North.

If direct labor costs for cultivation and harvesting grain at the 1953 mechanization level (according to approximate calculation norms) are taken into consideration, it becomes evident that in the North for one hectare of winter grain 190 man days are required, 100 in the non-chernozem center, and 93 in the chernozem center.

TABLE 2

Site quality of USSR climatic and soil conditions by areas (Data furnished by USSR Ministry of Agriculture)

USSR as a whole	1.0	The Urals	0.9	Ukrainian SSR	1.3
Northern areas	1.0	Western Siberia	0.9	Moldavian SSR	1.3
Northwestern areas	0.9	Eastern Siberia	1.0	Belorussian SSR	0.9
Non-chernozem center	1.0	Far East	0.9	Lithuanian SSR	1.1
Chernozem center	1.0	Central Asia	0.8[a]	Latvian SSR	1.3
Volga region	0.8	Kazakh SSR	0.7	Estonian SSR	1.2
Northern Caucasus	1.2	Trans-Caucasus areas	1.1	Karelian ASSR	0.9

[a] This includes irrigated fields under grain crops.

TABLE 3

Site quality scale for evaluation of USSR soil and climatic conditions, by autonomous republics, regions and districts (not included: Central Asia and Trans-Caucasus)

Site quality ratings	Chernozem and semi-desert									Non-chernozem areas					Site quality ratings
	Northern Caucasus	Ukraine and Moldavia		Chernozem center	Volga Region	Kazakhstan	Urals	Western Siberia	Eastern Siberia	North	Northwest	Non-Chernozem center	Belorussia, Lithuania, Latvia, Estonia	Far East	
		Right bank	Left bank												
150 and over	Krasnodar Region	Vinnitza, Kiev, Khmelnitsk													150 and over
140		Kirovograd, Chernovitsy													140
130		Moldavian SSR	Kharkov, Poltava				Perm, Sverdlovsk						Latvia		130
120		Ternopol, Volyn, Zhitomir, Lvov	Chernigov							Vologda			Estonia		120
110	North Osstein ASSR	Stanislav, Trans-Carpathia, Rovno	Stalino, Sumy, Zaporozhye, Dnepropetrovsk, Odessa	Kursk, Lipetsk, Mordvin ASSR, Chuvash ASSR				Tomsk			Kaliningrad	Kalinin, Yaroslav, Moscow, Ivanovo	Lithuania		110
100	Grozny, Stavropol' Region, Daghestan ASSR		Nikolayev, Izmail'	Voronezh, Tambov, Orel				Tyumen'	Irkutsk, Tuvin AO	Komi ASSR	Leningrad	Gorky, Ryazan', Kirov, Bryansk, Kostroma		Marine Region	100

TABLE 3—*Continued*

90	Rostov		Crimea, Lugan						Krasnoyarsk Region	Arkhangel'sk	Pskov, Novgorod	Smolensk, Vladimir, Tula, Mariysk ASSR, Tatar ASSR	Beloruss. SSR		90
80			Kherson	Penza	Kuybyshev, Ul'yanov	North Kazakhstan	Chelyabinsk, Bashkir ASSR, Udmurd ASSR	Kemerov, Kurgan, Osmk, Novosibirsk				Velikiye-Luki, Kaluga		Khabarovsk Region	80
70						Semipalatinsk, East Kazakhstan			Chita						70
60						Kokchetav, Kustanay	Orenburg	Altay Region	Buryat-Mongolian ASSR					Amur	60
50	Kamenka (area)				Stalingrad, Astrakhan'										50
40						Karagandin, Aktyubinsk, Akmolinsk, Pavlodarsk									40
30						Western Kazakhstan									30

TABLE 4
Preliminary estimate of illuvial plankton soils in the USSR

Site quality ratings	Northern Caucasus	Ukrainian SSR		Central Chernozem belt	Tatar ASSR & Southeast	Western Siberia and Kazakhstan	Altay (pre-Altay province)	Eastern Siberia	Non-Chernozem center	Far East	Site quality ratings
		Right bank	Left bank								
150–160	Leached Chernozems										150–160
140–150	Meadow Chernozem	Thick (typical) Chernozem; Podzolized chernozem (dark gray forest? gray forest?)									140–150
130–140	Pre-Caucasus Chernozem	Leached Chernozem (light gray forest); ordinary chernozem									130–140
120–130	Foothill Chernozems		Thick (typical) Chernozem								120–130
110–120	Carbonate Chernozems		Common Chernozem					Rich Podzolized Chernozem			110–120
100–110			Leached chernozem, (podzolized chernozem?)	Dark gray forest? (podzolized chernozem)		Leached & podzolized (forest-steppe) chernozems	Dark gray forest; light gray forest	Leached chernozem; rich chernozem; ordinary chernozem			100–110
90–100	(Eroded chernozem?)	Southern chernozem	Light gray forest? Southern chernozem	Gray forest; rich, chernozem, thick chernozem & ordinary chernozem		Dark gray solodized soils; leached meadow chernozem soils	Rich podzolized chernozem	Carbonate chernozem; meadow chernozem soil			90–100
80–90	Southern chernozem (chestnut foothill soils?)	Dark-chestnut soils	Dark-chestnut soils	Southern chernozem	Rich chernozem; leached chernozem	Leached (steppe) chernozem with medium humus content		Ordinary, slightly solonetzic chernozem	(Dark, thick meadow soil (sod-carbonaceous, typical and leached)		80–90

TABLE 4—*Continued*

70–80	(Low-humus chernozem on compact parent material?)		(Chestnut soils?)		Gray forest soils	Leached, rich chernozems; rich meadow chernozems; gray solodi soils			(Sod, slightly podzolic soils?)	Dark, medium thick meadow soil	70–80
60–70	Mountain chestnut & cinnamon brown soils				Ordinary chernozem	Carbonate chernozem; common chernozem	Leached chernozem		(Sod, medium and strongly podzolic soils?)	Dark-colored solodized, podzolized meadow soil	60–70
50–60						Southern chernozem	Ordinary chernozem; Southern chernozem			Brown forest	50–60
40–50					Southern chernozem, dark chestnut soils	Dark chestnut soils	Solonetzic chernozem soils				40–50
30–40					(Light chestnut soils?) Brown soils	Chestnut soils	Chestnut soils				30–40
20–30	Medium-columnar solonetz, chestnut zone							Sod and carbonaceous soils underlain with compact parent material at 30-cm depth; peat bogs; soils filled with boulders (over 100 cu m boulders per ha)			20–30
10–20	Crusty solonetz, chernozem zone										10–20
1–10	Crusty solonetz, chestnut zone										1–10
0–1	Malignant solonetz soils. Sandhills. Immature soils lined with solid rock at a depth less than 30 cm. Bogs and peats										0–1

NOTE: 1. The yield of grain crops, representing a USSR average for many years, is rated as a standard 100. Correction coefficients with supplementary ratings should be given in evaluating eroded soils on slopes and also soils of different textures. 2. Parentheses with question marks indicate soils for which yield data are insufficient, or soils placed in the table by interpolation.

These data show to what extent the cost levels for grain and the real costs for cultivation and harvesting differ. The same yields may be obtained on podzols and on sod podzols, but at the cost of a greater expenditure of work and resources (differential rent II).

TABLE 5

Tentative site quality ratings for USSR soils located on slopes and subjected to erosion by water

Soils	Correction coefficients for degree of erosion		
	Non-eroded (Thickness of humus layer not decreased by erosion)	Slightly eroded	Medium eroded
Sod podzolic, slightly and partly managed	1.0	0.5 ± 0.084	0.2 ± 0.093
Sod-podzolic, well managed reclaimed	1.0	0.7 ± 0.055	0.7 ± 0.104
Gray forest soils	1.0	0.5 ± 0.068	0.3 ± 0.012
Leached chernozem, (rich and thick layer?)	1.0	0.5 ± 0.036	0.2 ± 0.027
Ordinary chernozem	1.0	0.5 ± 0.073	0.2 ± 0.050
Southern chernozem	1.0	0.5 ± 0.061	(0.2?)
Chestnut soils	1.0	0.6 ± 0.067	(0.3?)

Note: Rating of principal soils (3) not subjected to erosion is rated 1.0.

TABLE 6

Tentative site quality ratings of USSR soils according to texture
(Correction coefficients by N. A. Kachinsky)

Zones, subzones and soils:	Clay	Fine clay loam	Medium clay loam	Coarse clay loam	Sandy loam	Sand with fine particles cohering	Sand with coarse particles
	Podzol Zone						
Podzolic-gley	0.4	0.6	0.8	1.0	0.8	0.5	0.3
Podzol only	0.5	0.6	0.8	1.0	0.7	0.5	0.3
Sod podzol	0.6	0.7	1.0	0.8	0.6	0.4	0.2
	Chernozem and semi-arid zone						
Gray forest soils	0.8	1.0	0.9	0.7	0.6	0.4	0.2
Chernozem: rich, thick and ordinary (leached?)	1.0	0.9	0.8	0.6	0.4	0.3	0.1
Chernozem: Southern, Azov and Trans-Caucasus	0.9	1.0	0.8	0.7	0.5	0.3	0.1
Dark chestnut	0.8	1.0	0.9	0.7	0.6	0.3	0.1
Chestnut and light chestnut	0.7	0.9	1.0	0.8	0.6	0.3	0.1
Brown	0.7	0.8	1.0	0.7	0.5	0.2	0.1

It is the task of economists to study the site quality scales, using Marx's and Lenin's teachings on differential rents I and II as a basis for this, and to consider the real costs of production and net costs as well as the more profitable crops (sugar beets, flax, potatoes, etc.), and other economic factors. This work is of vital importance and will comprise the next stage in economic land evaluation. It will be done through consultation and with the direct participation of soil scientists. During the first stage of the work all soils of the USSR were grouped by the V. V. Dokuchayev Soil Institute according to zones and provinces, into agroproduction groups according to fertility.

The second stage in site quality of soil was begun in 1957 by order of the Ministries of Agriculture of the USSR and the RSFSR. The V. V. Dokuchayev Soil Institute cooperated with the Council for Production Capacity Study of the Academy of Science, USSR and with the All-Union Scientific Research Institute for Agricultural Economics.

At present a comparative site quality scale for soils in the primary agricultural and natural zones is being compiled with diagnostic indices of these soils. A first tentative variant (Tables 4, 5, 6) has also been compiled. Here soil is considered a specific natural-historic entity, a means of production, and a product of labor. Special attention is given to the determination of agronomic soil properties and site quality is considered a precise agroproductional indicator of soil reduced to comparably quantitative characteristics.

For site quality of soil, i.e. for the determination of its comparative merits, the legend of the 1:1,000,000 State soil map is used, and local soil names are given in parentheses as synonyms. Use of a standard soil classification makes possible the synthesis of materials from different zones and districts in a standard site quality scale.

Long cultivation of soils, improvements and increase in soil fertility resulting from former agricultural practices and the work of preceeding generations, are not separated from natural soil fertility in the first stage of the work. Neither are deterioration nor decrease in soil fertility resulting from the same cause (erosion, secondary saline and bog soils, etc.).

The following principles are used in the compilation of the site quality scale for the entire USSR, for republics, zones, and areas: taken as a basis is the average of grain yields for a given period (in dynamics) for the country as a whole and the average soil properties, the yields of which most nearly approximate the average yields throughout the USSR. (The ordinary chernozems of the Central Chernozem Areas are taken as a standard). This average grain yield throughout the country is studied according to dynamics for four periods: 1) peasant ownership prior to 1914, 2) collective and state farms prior to 1941, 3) collective and state farms after 1947, and 4) experimental plots during the past 15–20 years. The average perennial grain yield is considered reliable only if calculated for a period of not less than five years. To compare the chemical and physical properties of soil in the compilation of the site quality scale for 100 (i.e. the standard) the properties of ordinary chernozems of the Central Chernozem Areas (Voronezh and Tambov Oblast's) are taken, the yields of which most closely approximate the average yields throughout the USSR.

In compiling the comparative site quality scale, special attention was given to data from experimental plots with exact soil characteristics and the results of testing the standard types of grain crops for two, three, and even four five-year periods.

During the first stage of the work soils of experimental plots with reliable data on average grain yields of a standard type were used as a basis for the site quality scale of USSR soils. Names of the experimental plot soils were adapted by the V. V. Dokuchayev Soil Institute and the USSR Ministry of Agriculture in agreement with the legend of the 1:1,000,000 State soil map. (Local soil names shown in the experimental plots' soil maps were retained as synonyms and entered in parentheses). In each zone and province the Soil Institute collected data on soil structure (depth of basic genetic horizons, etc.), texture, parent material, depth of effervescence, and, if possible, all analytical data characterizing the chemical and physical soil properties. Agricultural history and methods (including fertilization) were taken into account as far as possible and soil areas for each region were computed. The Soil Institute simultaneously processed mathematically the obtained yield data for the principle USSR soils in order to determine the reliability of the site quality ratings.

Comparative yields, calculated according to scale, where the average grain yields for several years in the USSR is designated as 100 were taken as site quality ratings. For experimental plots this was 21 centner/ha., for collective farms 9 centner/ha.,[1] for peasant holdings prior to 1914, 8 centner/ha., and for earlier periods 7 centner/ha. The site quality scale for principal USSR soils (Table 4) is compiled with intervals of 10, e.g. 90–100, 100–110, etc. The site quality ratings extend from 0 to 160.

During mathematical processing it was established that the criterion of reliability for values of average yields in the experimental plots will fluctuate between 1.8–2.8 centner/ha., thus comprising about 10% of the yield value when the average yield is 21 centner/ha. The intervals on the site quality scale which are less than 10 will therefore fall within the range of experimental error. Further research by the zonal institutes will make the scale more precise and the intervals smaller.

The next stage consisted in compiling a series of auxiliary scales for erodibility, texture, salinity, swampy (gleying), parent material, depth to compact horizon, relief, etc. These auxiliary site quality scales give corrective coefficients for the basic evaluation scale for principal USSR soils of clay loam textures. A scale has also been compiled for site quality of soil according to erodibility (by the soil erosion laboratory), and a scale for soil texture (by N. A. Kachinskiy). Both scales are compiled on the 10—rating system with the rating of principal soil of the common site quality scale of the USSR designated as 1.0 (Tables 5–6).

Finally, the site quality scale must show soil distribution in the descending order of fertility, according to the relative average grain yields for several years at the normal agrotechnical level of a given zone. As pointed out, 100 is designated as the average grain yield in the USSR at varying agricultural levels (but common to the country as a whole) and all yields of individual soils are calculated in comparative terms of this basic value, but at comparable agrotechnical levels.

It must again be pointed out that the former site quality scales and classifications of natural soils which classified soils in a descending order of fertility considered this fertility as "something unchanging, permanent, eternally given." (4, p. 304). This led to mechanistic, abstract inventions, the productional uselessness of which soon became manifest.

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[1] "Socialistic Agriculture in the USSR". Statistical symposium. Central Accounting Administration for State Planning of Agriculture in the USSR. Gosplanizdat, Moscow-Leningrad, 1939, p. 61.

In order to avoid former errors, soil fertility according to dynamics for a series of years was taken as the basis for the comparative scale of USSR soils, at a varying agricultural level, but one common to the entire country. In the past, soil scientists compiled large-scale soil maps of collective and state farms and gave detailed agronomic characteristics of individual soils, soil complexes, and combinations. They also suggested methods for increasing yields. This work has lost none of its former value, but is complemented by the site quality of soil. Site quality of soil must depend both upon the precise large-scale soil maps of the collective and state farms and regions, and on soil research, disclosure of agronomic properties, and research in agricultural management conditions. From the comparative site quality of soils and soil research there must result a methodical system for increasing soil fertility, for bringing about high and stable yields, and creation of material incentive on the part of collective and state farm workers and specialists in soil fertility and improvement. Site quality of soil in no way supersedes soil surveys, compilation of soil maps, development of agronomic soil characteristics or methods for increasing yields. It simply complements these and develops untapped resources.

From the tentative evaluation scale of principal USSR soils, it is evident that the site quality of the same soil subgroups varies in different provinces, e.g. the leached chernozem of the northern Caucasus is rated at 150 to 160, that of the right-bank Ukraine at 100 to 110, that of the Southeast at 80 to 90, while in western Siberia it again goes up to 100 to 110. Such variations in the ratings of the same soil subgroup in different soil-climatic provinces are to be explained primarily by climate aridity. By introducing agrotechnical methods to increase soil moisture and by careful application of these methods, yields in the Southeast may be increased. According to longstanding data of experimental plots in the Southeast, snow retention will increase yields by from 25 to 150%. Yields in the Southeast may be doubled by the introduction of bare and side fallows, snow retention, retention of runoff from snow melts in fields before spring harrowing, weed control, and many other methods. Irrigation of chernozems in the arid regions has been planned, but this necessitates labor and resources, i.e. it depends upon obtaining differential rent II.

Attention is called to the sod podzolic soils of the non-chernozem center which have a rating of 60–90. (Table 7, also controlled experiments under the supervision of Lebedyantsev). The well-managed sod medium and strongly podzolic of the State experimental plots have a rating of 100–110, while the well-managed sod slightly podzolic have a rating of 120–130, considerably surpassing the average USSR yields

In well-managed experimental plots with advanced agricultural practices and where sod slightly podzolic soils are fertilized, the average grain yield for many years is 26 centner/ha. (average for six experimental plots). In sod medium and strongly podzolic coarse and medium clay loams, grain yields average 23 centner/ha. (average for 29 experimental plots). Thus there exist in the non–chernozem belt, as well as in the Southeast, great source reserves for increasing yields. The systematic use of organic and mineral fertilizers together with sufficiently developed agricultural practices will be able to guarantee high and stable yields in the sod podzolic soils of the non-chernozem belt. This has been verified by the many years' experience of the State experimental plots. As in the Southeast, however, this is a problem related to differential rent II.

Through differential rent II, the introduction of supplementary methods for increasing soil fertility may thus considerably raise site quality of soil both in the arid regions with rich soils and in moist regions with poor soils, as is evident from the supplementary site quality scales. In slightly and medium managed sod podzolic soils, for example, erosion lowers yields drastically. If the yield is designated by 1.0 on non-eroded soil, on slightly-eroded soil the yield will be 0.5, and on moderately-eroded soil it will be 0.2. If sod podzolic soil is well managed, organic and mineral fertilizers are systematically applied, and grassland crop rotation leaves a large root residue in the ground, the fertility difference between non-eroded soils and soils in various stages of erosion will be somewhat equalized. If we designate the yield of well-managed non-eroded sod podzolic soil by 1.0, the yield of slightly- and medium-eroded soil will be 0.7.

This regularity can be observed in the effect of soil textures on yields at various stages of management. According to the site quality scale

(Table 7), the yields of sod podzolic medium clay loams is designated by 1.0, while that of sandy loam is 0.6. According to yields on the well managed sod podzolic coarse and medium clay loams of the experimental plots, the site quality scale is 109 (average grain yield 23 centner/ha.—several year average for 22 plots). The site quality scale for well managed sod podzolic sandy loams is 95 (several year average grain yield for 13 experimental plots being 20 centner/ha.). The difference in yields caused by different textures during management is spanned here, however, by means of differential rent II, i.e. by additional work and resources: the application of organic and mineral fertilizers, correct crop rotation of perennial legumes, and more efficient agricultural practices.

It should be pointed out that all these problems having to do with differential rent II have been insufficiently studied and that they require research in relation to qualitative site quality of soil by a collective of local scientists, zonal institutes, and experimental stations. An experimental site quality of soils should be made within the geographic framework of the better collective and state farms, and long-term, regular research should be made regarding the yields of main soil groups at different levels of agricultural practices in conjunction with more intensive soil-, agrochemical-, and economic investigations. Such joint research, carried on through the cooperation of the various scientific institutions, the central and local zonal institutes, the higher educational institutions, and experimental stations, will produce the most reliable data for specifications and for the perfecting of the site quality scale for USSR soils. Of special importance is the role of the zonal institutes and the experimental stations.

A standard site quality scale of soil for the different zones and provinces of the USSR with supplementary scales dealing with texture and erosion makes it possible to approach practical site quality problems on individual farms. This is shown by the following example of four districts in the Moscow region. For this type of site quality M. N. Malyshkin employed the following method: in accordance with research data from collective farms in the Klinskiy, Serpukhovskiy, Orekhovo-Zuyevskiy, and Serebryano-Prudskiy districts of the Moscow region, (work of the soil team of the Moscow Region Land Exploitation Administration), soil tracts were rated according to basic agricultural yields for each collective farm of these districts. The ratings showed that on the large scale soil maps 236 various soil types were described in the collective farm land under cultivation alone. Of these, for example, 33 variants were given for sod podzolic soils according to texture, parent material, degree of gleying, swampiness, erosion, etc. A site quality rating of basic soil variations was made according to the basic scale, e.g. slightly sod podzolic—80–90. In all instances the highest indicator of the series was used, i.e. in the given instance—90.

By introducing corrective coefficients for texture and erodibility, site qualities were determined for the different variants of basic soil. Thus, in determining the site quality for a slightly sod podzolic soil of a coarse clay loam, the basic rating of 90 was multiplied by the corrective coefficient 0.8, which gave this soil a rating of 72. Obvious difficulties were encountered when evaluating such soil variants as coarse clay loams on sands, or sandy loams on clay loams, etc. In this connection it is hoped that the processing of all the corrective coefficient supplementary tables which more accurately define the site quality of soil of individual farms will be soon completed.

If slightly sod podzolic coarse clay loam was found on a slope and subject to erosion, its site quality rating of 72 (if slightly eroded) was multiplied by the coefficient 0.5 and thus received a rating of $72 \times 0.5 = 36$.

By multiplying the site quality of soil by the plowed area which it occupies, a portion of its tillable capability was estimated and the sum of all evaluations gave an overall estimate of all the plowlands of the collective farm, region, etc. If this sum is divided by the entire plowland area, the average site quality of the collective farm, region, etc, is obtained.

The results of these ratings showed that site qualities of the collective farms of the Serebryano-Prudskiy district may be evaluated at a rating of 89, those of Serpukhovskiy district—66, Klinskiy district—54, and Orekhovo-Zuyevskiy district—37. It will be more than twice as difficult to obtain the same yields in the collective farms of the Orekhovo-Zuyevskiy district as in those of the Serebryano-Prudskiy district, etc.

By comparing the average yields of the collective farms of these districts for the past 8 years

TAB

Tentative soil quality rating scale for soil-climate conditions of union and
(Excluding Central Asia

Site quality ratings	Chernozem and semi-desert belts						
	North Caucasus	Ukrainian SSR, Moldavian SSR		Chernozem center	Povolzh'ye	Kazakhstan	Ural
		Right bank	Left bank				
170–180		Kirovograd	Zaporozh'ye Stalinsk				
160–170	Krasnodar Region	Cherkassk, Nikolayev	Poltava				
150–160		Odessa	Krym				
140–150		Vinnitsa	Sumsk, Khar'kov, Dnepropetrovsk (Kherson?)				
130–140		Khmel'nitsk, Chernovits	Lugansk				Sverdlovsk
120–130		L'vov, Ternopol'	Chernigov				
110–120		(Kiev?), Rovno, Zakarpat'ye, Stanislav, Moldavian SSR		Voronezh, Kursk, Belgorod			Chelyabinsk
100–110	Rostov, N. Osetian ASSR, Stavropol, Region			Tambov			
90–100	Kamensk	Volyn' Zhitomir		Balashovsk, Lipetsk, Penza		North Kazakhstan (East Kazakhstan?)	Perm
80–90	Groznyy	Drogobych		Orlov	Ul'yanov	Kokchetay Semipalatinsk	Bashkirian ASSR
70–80	Kabardinian ASSR				Tatar ASSR, Kuybyshev	Kustanay, Karaganda	Udmurd ASSR
60–70	Dagestan ASSR				Saratov	Akmolinsk, Paylodar	
50–60					Stalingrad	Aktyubin	Orenburg
40–50						Western Kazakhstan	
30–40					Arkhangel'sk	Gur'yev	

with the established soil site quality, it becomes apparent that the Serebryano-Prudskiy district is far from exhausting its possibilities. As far as yields are concerned, it is at the level of the retarded districts. The collective farms of the Klinskiy district, on the other hand, approach the yields obtained by the experimental plots through site quality of soil. This is due to the successful utilization of legumes by the collective farms of this district.

Beside the incomplete utilization of natural soil fertility in these districts, a lowering of yields on soils subject to erosion, swampiness, etc, is also to be observed. For example, the collective farms of the Klinskiy district lose approximately 30% of their possible yields because of erosion, while in the Serebryano-Prudskiy district these losses amount to 48% of the yield.

This example allows us to make a comparative analysis of progress in the management of agricultural enterprises and of the district as a whole. By supplementing site quality of soil with an evaluation of the territory, i.e. a determination of relief, stoniness, and other factors in plowlands, we can arrive at a more detailed comparative analysis of the activity of each collective and state farm.

It is above all essential to supplement and more precisely define the site quality scale of principal soils for individual zones and groups

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autonomous republics, districts and regions of the USSR and Transcaucasus)

		Non-Chernozem belt					
Western Siberia	Eastern Siberia	North	Northwest	Non-Chernozem center	Belorussia, Lithuania, Latvia, Estonia	Far East	Site quality ratings
							170–180
							160–170
							150–160
						Primorskiy Region	140–150
Kemerovo	Irkutsk						130–140
Tomsk	Krasnoyarsk Region						120–130
Tyumen'sk, Kurgan	(Tuvinsk AO?)					Khabarovsk Region	110–120
Omsk				Moscow, Chuvash ASSR	Latvian SSR, Estonian SSR	(Kamchatka?)	100–110
Novosibirsk, Altay Region	Yakutsk		(Murmansk?) Kaliningrad				90–100
	Chita		Leningrad	Ivanovsk, Kalinin, Tula, Yaroslav	Lithuanian SSR	Amur	80–90
	Buryat-Mongolian ASSR	Vologoda		Bryansk, Arzamassk, Vladimir, Gor'kiy, Kirovsk, Mari ASSR	Belorussian SSR		70–80
		Arkhangel'sk, Komi ASSR	Karelian, Novgorod, Pskov	Ryazan' Smolensk, Kostroma, Velikiye Luki, Kaluga		Sakhalin	60–70
							50–60
							40–50
							30–40

of provinces, as well as the corrective coefficient scales for degrees of erodibility and texture. It is also essential to compile corrective coefficient scales for the non–chernozem belts for degrees of gleying, and for the chernozem belts for degrees of solonetization. Corrective coefficient scales must be compiled having to do with the character of the parent material, relief, and exposition. Other scales must be compiled which express local soil peculiarities and fertility. Such scales should also be compiled for basic technical crops: sugar beets, flax, potatoes, etc., as soil fertility is inseparable from plants.

A standard, proven, site quality scale for USSR soils for grain and other basic technical crops, compiled on a sound scientific basis is not only of great practical value, but of great value from the standpoint of theory and is a great aid in advancing the classification problem in soil science. Soil is not only a specific natural-historic entity, but is also a product of labor. The present stage of the soil formation process is the stage of man-directed soil transformation. These branches of theoretic soil science, exceedingly important from the practical standpoint, have hitherto been insufficiently developed. Through site quality of soil these problems will be more thoroughly studied. Agricultural activity can either hasten or retard the soil transformation process. Cultivating sod podzolic soils with heavy applications of organic and mineral fertilizers, liming, sowing perennial grasses, and correct crop rotation accelerate the humus process and create soils with high fertility. In the forest-steppe sugar beet growing districts of the Ukraine, where intensive fertilization has been carried on for more than a hundred years, or in the Baltic Republics, where crop rotation, sowing perennial grasses, and intensive fertilization have been the rule for more than a hundred years, great soil areas of high fertility have been created. Incorrect soil utilization practices, however, may lower soil fertility and retard the soil formation process. In certain cases it may even cause "rejuvenation" of soils to a state approaching the parent material as, for example, in highly eroded soils where yields have dropped by 50–80% and more.

The present phase of the soil formation process which is linked with man's economic activity is a stage in the one great soil formation process. The study of this phase, closely connected with site quality of soil, is of exceptional scientific interest.

Site quality of soil must create a powerful impetus toward further agricultural improvement. In the compilation of local site quality scales of soil, scientists, agronomists, and economists must discover methods for the most productive use of each parcel of ground. Site quality of soil must arouse a material incentive in collective farm workers and in agricultural specialists, not solely from the standpoint of maintaining soil fertility, but from the standpoint of constantly increasing it as well. It must introduce concrete methods for increasing yields throughout all the various conditions of our country.

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FACTORS IN SOIL FORMATION AND THE SOIL-FORMING PROCESS[1]

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RESEARCH development in the form of direct study of soil processes is a characteristic and important trend in contemporary soil science. Successful development of this trend requires a quantitative study of the phenomena constituting the soil-forming process, and also the relation of this process to its environment, i.e. the factors in soil-formation.

Hence the necessity of developing ideas both on the soil-forming process and on its factors as a basis for the quantitative study of all these phenomena. This problem is the subject of the present paper. The ideas put forward in it, as will be seen, are based entirely on the teachings of V. V. Dokuchayev regarding soil formation and its factors.

In Dokuchayev's teaching on soil formation factors two concepts were developed: 1) the part played in soil formation by the elements of external media (climate, parent material, living and dead organisms, relief) and, 2) the development of soils through time (the age of the region). In his earlier works Dokuchayev called the factors of medium "producers" (3, p. 72) "soil forming conditions" (3, p. 210), or "agents of soil formation" (4, p. 245). He later begins to call them "soil forming elements" (6, p. 303), "soil forming factors" (5, p. 284) or simply "soil-formers" (6, p. 303).

The concept of the influence of all these conditions on soil formation was first ("entirely *a priori*", as Dokuchayev himself recorded later) presented in 1877 in his paper "Conclusions on the Russian Chernozem" which was written on the basis of his knowledge of the literature data, prior to his numerous investigations (2, p. 64). The idea was further developed in a series of works and quite clearly formulated when in 1881 he wrote that soils "are substances consisting of organo-mineral formations occurring on the surface and always more or less markedly colored by humus; these substances always have their natural origin, and are always and everywhere a result of the combined activity of parent material, living and dead organisms (both plant and animal), climate, age of the region and local relief. . ." (5, p. 260).

Later, in the paper "Our Steppes Then and Now", which lists "the basic factors underlying agriculture. . .", Dokuchayev stressed their interrelationship when he put forward the concept of the reversible influence of soils on other natural substances (8, p. 97). At a later stage in his work Dokuchayev begins to fix the boundaries between various "soil-formers" according to their nature and the part played by them in soil formation. He deals with this problem in several works of the 1898–1899 period (9, p. 379; 11, p. 415; 13, 434; 14, p. 262). He writes (13, p. 434) that the soil ". . . is a *product* of the collective activity of the following *soil-forming factors:* the *climate* of the given region, plant and animal *organisms* and, finally, the *parent material* on which the soil lies at present. In other words, soil is a *function* of the three *soil-forming factors* mentioned previously, multiplied by time or *age* of the soil, and this viewpoint is fundamental to the contemporary soil science . . .".

Thus Dokuchayev clearly distinguished parent materials, climate and organisms as factors in soil formation from the age of soils and, from relief, which he named a *condition* (my italics—A.R.) of soil formation (14, p. 267).

It should be noted that during the same period Dokuchayev attempts to express in some measure the concept that climate is a factor in soil formation. Thus, in the paper "Primary and Eternal Conditions for the Life of Man and his Culture" (10, p. 375) Dokuchayev speaks not of climate, but of "water and air" in enumerating the three main factors in soil formation and boundaries between them. In another paper (11, p. 422) on climate, he puts in brackets: "(water, temperature, oxygen, carbon dioxide of the air etc.)".

While distinguishing the three main soil-formers Dokuchayev still adheres to the concept expressed by him as early as 1881 (7, p. 318) of the equal importance of all the soil-formers in the soil-forming process. In one of his last papers (14, p. 264) he says: "It is quite useless to try to decide which of the soil-formers played the most important part in the history of soil formation. They are all equally important".

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[1] Paper presented at the 5th commission of the Moscow section of All-Union Society of Soil Scientists.

Dokuchayev's teaching on factors in soil formation was developed in the works of N. M. Sibirtsev, whose particular achievement was the clear formulation of the concept of the interconnection of various types (forms) of soil-forming factors or ". . . similar combinations of soil-formers" (18, p. 292; 19, p. 309).

We will discuss the concepts presented by Dokuchayev at the end of his scientific activity, and distinguish factors and conditions of soil formation. We will begin with natural factors in soil formation, and later discuss the part played by man.

The soil-forming process, like other natural processes, represents a combination of interconnected phenomena of transformation and translocation of matter and energy taking place in the soil. Besides being a specific process, it is a link (soil link) in a wider process—the cycle of matter and energy taking place in the biosphere. The connection between these processes is explained by the fact that between the soil and other natural substances an exchange of matter and energy takes place, accompanied by a transformation of the latter. And we are justified, when trying to explain the part played by these natural substances in soil formation, in separating in our minds the phenomena taking place in the soil itself, i.e. the process of soil formation, from the phenomena of interaction between the soil and the substances previously mentioned. *We propose to call these natural substances with which the soil is connected by exchange of matter and energy, the factors in soil formation. Such substances are: parent material, atmosphere, sun and living matter (living organisms).* The role of these natural substances in the process of soil formation will be examined in more detail.

The role of parent material in soil formation is twofold. First, this parent material is a source of the minerals from which the main mass of developing soil is formed. It was in this sense that the material was named "parent material" by Dokuchayev. It undergoes a series of changes in its physical state and its textural, chemical and mineralogical composition while being converted into soil. In addition to this, the soil inherits a number of characteristics from the parent material. This "transmission by heredity" (in spite of changes during the soil-forming process) constitutes one of the forms of its influence on soil formation and on the characteristics and composition of the soil being formed.

The second form of its influence arises from the fact that an exchange of matter and energy takes place between the soil and the parent material occurring beneath it—always a two-way exchange of thermal energy, gases and water vapors—and also an exchange of solutions, either two-way or single direction—from the soil into the soil material or vice versa.

These two forms of the participation in soil formation are realized jointly and simultaneously, but their relative importance changes during the soil development process. During the period of soil genesis, the first form is of greater importance, while during subsequent soil development the second form exercises a more profound influence. In view of the fact that the "parent" role of the material is of secondary importance during the processes which take place in the already formed soil, it would be more accurate to give this factor a different name, for instance "soil material".

We now turn our attention to *climate* as a factor in soil formation. However, in view of the insufficient definiteness of the concept of "climate", the form taken in its participation in soil formation and the need for quantitative evaluation of the phenomena involved in this factor, we propose to substitute for it two other factors, which are natural entities—*atmosphere* and *sun*. The combination of these, as regards the extent of the phenomena related to them, exceeds to some extent Dokuchayev's concept of "climate" as a soil formation factor and yet fits in with his attempts.

The part played by *atmosphere* as a natural substance in soil formation is expressed in an exchange of radiant and thermal energy, dust, salts, moisture and gases between it and the soil. These forms of exchange are as a rule two-way; under certain conditions, however, some may acquire a sharply expressed asymmetry or may even turn into a one-way flow of matter or energy. Thus, in gaseous exchange, for instance, the flow of O_2 from the atmosphere into the soil and the flow of CO_2 from the soil to the atmosphere predominates. In the presence of forest vegetation the deposition of dust from the atmosphere on to the soil etc. predominates.

Sun is a source of radiant energy which enters the surface of the soil and the vegetation cover. This process is one-way, as is the reverse process of soil radiation into cosmic space. Part of the radiant energy absorbed by the soil is transformed into thermal energy which is subsequently used 1) in heating the atmosphere, 2) in the evaporation of soil moisture, and 3) in heating the soil.

The consumption of heat in warming the air is one of the forms of energy exchange between the soil and the atmosphere. The heat used in warming the soil produces in the latter a corresponding temperature regime. It spreads in the soil by two systems of waves, with diurnal and annual cycles. Moreover, the mean annual balance of this heat is equal to zero—it is eventually used completely in radiation and emission into the atmosphere. The heat used in the evaporating soil moisture is a more complicated case. A great part of it is converted into latent heat in vapor formation and dissipated into the atmosphere with water vapor, representing one more form of energy exchange between soil and atmosphere. Another part is consumed in the removal of liquid moisture from solid particles of soil, which is accompanied by an increase in the latter's suction force. This suction force may take a meniscus or sorption form, depending on the soil moisture status. With drying out of the soil the second of these two forms replaces the first. The osmotic pressure of the latter rises as a result of increased concentration of soil solution during the evaporation process. Since the most intensive drying-out occurs in the topmost soil layer, the gradient of the suction force is found to be directed upwards. Thus a trend towards an upward translocation of soil solution is produced, the rate of which depends on the water-conductivity of the soil, and hence on its moisture content.

Living matter (*living organisms*) as factors in soil formation ("*biological factor*") can be subdivided into two main groups: 1) the higher green plants and 2) the higher vertebrates. The lower plants (bacteria, fungi, actinomycetes) and minute invertebrates (arthropoda, their larvae, molluscs, vermes, protozoa) enter into the soil composition; their activity will be discussed when the soil-forming process is examined.

The participation of the *higher green plants* in soil formation is brought about in two principal ways: a) through interaction between the soil and plant root-system taking place on the surface of the latter, and b) through the deposition of plant materials to the soil surface. We shall examine a) first.

A proportion of the radiant energy from the sun enters the surface of the leaves producing evaporation of moisture from them (transpiration), resulting in a decrease in water-diffusion pressure in the leaves. This decrease, as physiological researches show (15), is directly transmitted through the vessels into the roots and beyond them to the moisture in the soil. A passive moisture flow from the soil into the plant arises, resulting in decreasing soil moisture and a consequent increase in the suction force of the soil, so that a gradient of this force is produced in the soil. This suction force may have a meniscus or sorptive nature depending on the soil moisture status; and, depending on the difference in the absorption rate of moisture and of salts occurring in the soil solution, a gradient of osmotic pressure may be produced in the latter. Radiant energy from the sun penetrates into the soil through the agency of higher plants and produces there, after transformation into other forms, a gradient of suction force directed into the rhizosphere, the value of which increases from below (where there are fewer roots) upwards (where there are more).

In addition to moisture absorption, roots extract nutrients from the soil; the mechanism of the absorption of these is different and is mainly based on exchange reactions, with emission of H and HCO_3^- ions by plants. Under specific conditions plants can also secrete organic acids. The absorption of nutrients is not a one-way process—a secretion of nutrients from roots into the soil is observed. Quantitatively, however, the absorption of nutrients, moisture and oxygen by plants from the soil and the inverse secretion of carbonic acid (H^+ and HCO_3^-) predominates. Selectivity—"biological sorting", in Polynov's phrase (16)—is important in the absorption of nutrients by plants. This selectivity is expressed in the fact that nutrients are not taken up by plants in the same proportions as they occur in the soil or even in soil solution. As a result, the flow of salt nutrients entering plants is enriched in phosphorus, sulphur, nitrogen, calcium and potassium and impoverished in sesquioxides. Such are the phenomena taking place on the contact surface of roots and soil.

We shall now discuss the second principal participation of green plants in soil formation—associated with photosynthesis.

As is well known, a proportion of radiant energy entering the surface of green plants is collected and utilized by them for splitting the water molecules and for further synthesis of organic compounds, in which this energy is fixed in a form of chemical energy. This process takes place outside the soil. However, as whole plants or their separate parts die off, the plant residues enter the surface and top layer of the soil and their organic compounds become a component part of the soil. In this way carbon previously contained in the atmosphere (as was stressed by Vernadskiy [1]) in the form of unstable organic compounds rich in chemical energy, is involved in the process of soil formation.

Thus the higher green plants play the part of "agents" in the exchange of matter and energy between soil and sunlight, soil and atmosphere, surface layers of the soil and the other layers. This "agency", however, is by no means passive, as the exchange is accompanied by a *transformation* of both matter and energy. Plants produce and actively maintain several interrelated currents of matter and energy: 1) the flow of salts from deep layers of the soil into its surface and upper layers; 2) the flow of organic substances (synthesized from soil nitrogen, soil moisture and carbon in the atmosphere) towards the soil surface and upper layers; 3) the flow of radiant energy (transformed into its other forms) into the soil; 4) the flow of carbon dioxide from the soil into the atmosphere; 5) the flow of oxygen from the atmosphere into the soil; 6) the flow of moisture from the soil into atmosphere.

All these phenomena are, first of all, necessary for soil formation. Secondly, they can be brought about only by the higher green plants possessing the capacity for photosynthesis and the capacity for biological sorting of salt nutrients and nitrogen compounds. Thirdly, these phenomena embrace the most essential aspects (quantitatively and qualitatively) of the soil formation process and result in the emergence and development of soil *fertility*.

For these reasons we regard the biological factor, in particular activity of the higher green plants, as the *leading* factor.

Next we will discuss the part played by the *higher animals*—chiefly burrowing rodents—in soil formation. These animals are not found in all soils. They produce displacement along their paths ("crotovines") within the soil and also encroach on the parent material, thus producing an exchange of solid particles between the soil and its parent material. The volume of soil and parent material shifted and the thickness of the soil layer involved in these phenomena may vary widely, depending on the species and number of animals. These animals may be a very important component of the biological factor. For instance, when they throw parent material containing salts to the surface, by this means they produce a complex soil cover in which solonetzes play a part.

In addition to factors in soil formation, *conditions of soil formation* such as gravitation and relief should be distinguished.

The *gravitational field* of the Earth (which we can regard as roughly constant in value and direction) produces a continual tendency of downward movement by all the soil constituents.

However, various sources of energy underlay the downward movement of soil constituents. The mass of mineral soil particles occurring at a specific altitude possess a corresponding gravitational energy reserve. This reserve is produced at the expense of those forces raising the mass to the given altitude—in the overwhelming majority of cases—of tectonic forces. This reserve may be augmented during epeirogenetic upheaval and reduced during epeirogenetic subsidence or denudation without losing its original nature.

The matter differs with soil solution, which is continuously renewed because of precipitation. The reserve of gravitational energy inherent in this solution has as its source the radiant energy of sunlight. The latter, by causing an ascending movement of vapor-formed moisture in the atmosphere, increases the reserve of gravitational energy inherent in this moisture, moving it downwards as far as sea level.

Relief, the form and relative position of the soil surface is another important condition in soil formation. The relief brings about matter and energy redistribution on the soil surface, thereby affecting the amount of water and heat turnover in the soil. The angle and direction (exposition) of the soil surface gradient affect the amount of radiant energy entering the unit of soil surface and consequently the amount of its heat-turnover, temperature regime, rate of snow-thawing, and so forth.

Furthermore, the gravitational field of the Earth, acting through the relief, brings about a redistribution of moisture in atmospheric precipitation. The slope of the soil surface causes a dispersion of gravity force and the accumulation of water which augments the gravity force. As a result of this the mass of water begins to run off down the slope at a rate depending on its angle, so that the amount of moisture entering the soil on convex elements of the relief decreases and that entering on concave elements of the relief increases.

In reference to the relief as a condition in soil formation, we should bear in mind not only the external relief—the surface exposed to daylight—but also the *internal relief*—the form and relative position of the various soil and parent material layers, which has a bearing on the development of soil runoff and percolation. Terrestrial gravitation and relief, both external and internal, are conditions which make possible movement of substances between adjoining masses of various soils. This movement is, as a rule, one-way and asymmetrical, being directed downwards along the slope.

Direct participation of one factor or another comprises, as we have seen, an exchange of matter and energy between a given natural substance (factor in soil formation) and the soil.

Indirect participation of one factor or another (natural substance) is shown in its effect on the exchange of matter or energy between the other substances (factors) and the soil. The falling of rain on the soil surface is an example of direct participation by the atmosphere in soil formation. The retention of part of the precipitation on treetops is an example of indirect participation by plant cover (the biological factor) in soil formation. The influx of radiant energy into the soil surface and the exchange of moisture and heat between soil and atmosphere are examples of direct participation by sunlight and atmosphere in soil formation. At the same time the temperature and water regimes established in this process determine the possibility of the emergence of plant associations of various types and of their make-up as regards species. This is an example of the indirect effect of the first two factors on soil formation through a biological factor. The combination of factors and conditions in soil formation may be termed the *soil-forming medium*.

The *age* of the soil ("the time factor") has not been mentioned among the factors or conditions in soil formation, since time together with space is one aspect of the existence of any substance. The process of soil formation, taking place in time, results in the development (evolution) of the soil, which is linked with the development (evolution) of other natural substances, particularly of living organisms. This problem has been considered by us in detail (17).

A quantitative, and consequently precise, study of the parts played by various factors in soil formation seems possible on the basis of the distinct forms of interrelation between the soil and the factors in soil formation expressed in an exchange of matter and energy outlined by us (albeit schematically).

Next, we will examine the nature of soil formation, that is, the phenomena which take place in the actual soil layer.

The independence of the soil as a natural substance, established by Dokuchayev, makes it necessary to consider *all phenomena occurring in the soil, without exception, as components in the process of soil formation.* These phenomena are extremely various but are closely interrelated. They can be divided into nine groups embracing the most important aspects of the soil-forming process.

Disintegration of Primary Minerals. The phenomena in this group may have a physico-chemical nature, but apparently occur more often with the participation of organic compounds and even with the direct participation of microorganisms and to some extent with the roots of the higher plants.

Disintegration and Synthesis of Secondary Minerals. The disintegration of secondary minerals always takes place with the participation of organic matter—particularly organic acids—and perhaps with living organisms. In the synthesis of secondary minerals a greater part may be played by phenomena of a physico-chemical nature, although there are indications of the formation of mineral crystals in the cells of the higher plants.

Decomposition and Synthesis of Organic Compounds (including Humification). The phenomena in this group take place mainly with the direct participation of living organisms; microorganisms producing organic matter decomposition by means of ectoenzymes, and lower animals pulverizing organic residues and digesting them by means of enzymes. At the same time the formation of various organic acids is very important. Their synthesis may take place both with the participation of microbes and higher animals and with the direct participation of living organisms, but always with participation of organic compounds. The biological fixation of nitrogen and transformation (ammonification and nitrification) of its compounds should be mentioned here separately.

Decomposition and Synthesis of Organo-Mineral Compounds. Synthesis takes place chiefly by physico-chemical means, but invariably with the participation of organic compounds. Microorganisms play a direct part in decomposition.

Ion Exchange between Soil Solution and the Solid Part of the Soil. We are dealing here with phenomena principally of a physico-chemical nature but often taking place with the participation of organic compounds.

Solution and Peptization, Precipitation and Coagulation. These phenomena are mostly physico-chemical, but organic compounds often play a part in them.

Descending and Ascending Movement of Solutions. This is accompanied, respectively, by the leaching of soluble compounds or by their accumulations (*alinization*). These phenomena are mainly of a physical nature, although the gradients of the forces producing the ascending movement of solution may be created by higher plants.

Wetting and Drying. Wetting is always a physical process, and drying physical and biological.

Heating and cooling. These phenomena are of a physical nature and can be accompanied by freezing and thawing.

We can proceed to classify these phenomena in three classes: 1) phenomena brought about with direct participation of living organisms; 2) those brought about with participation of organic substances—of the products of living organisms, but without direct participation of organisms; 3) those brought about without participation of organisms or of their product.

Thus we see that a great part of phenomena of soil formation take place with direct participation of living organisms or their products. This determines the leading part played by organisms in soil formation. The phenomena described, however, always coexist and interact with other phenomena occurring without the participation of organisms but are just as essential to the soil-forming process in the forms in which we observe it. It is in this coexistence and interaction that the main feature of the soil-forming process, distinguishing it from other natural processes, consists. Soil formation, always composed of interrelated phenomena of the three types indicated previously, is a process *sui generis*,—a process of a specific type, corresponding to the concept of the soil as an "organo-mineral formation" (5) or "biological-mineral system" (1).

Returning to our classification of the main phenomena constituting soil formation, we see that each of these groups except the first (irreversible decomposition of primary minerals) is composed of phenomena mutually contrary in their nature and direction. This is extremely important in leading us to the concept of the essence of the process of soil development as an interchange and interaction ('struggle') of the mutually contrary phenomena described.

The main causes of this interchange are the cyclical nature of the development of the organisms and the triple (diurnal, annual and perennial) rhythm in the influx of the radiant energy of sunlight into the surface of the Earth, the most important of these rhythms being the annual, by virtue of its amplitude. Against the background of these cyclic rhythms an important part is played by the interchanges of contrary phenomena not possessing a regular periodicity, for instance precipitation, increase and decrease of cloudiness, etc.

The groups of main phenomena constituting the examined soil formation process occur in all soils without exception, regardless of type. This, together with the predominance of the biological factor over other factors in soil formation and over biological phenomena in the actual process of soil formation determines the *unity* of the soil-forming process.

We must now consider the problem of causes of the diversity of soils in view of the unity of the soil-forming process.

The causes of this diversity lie, as is well known, in the variability of the factors affecting soil formation, namely:

1) the diversity of parent materials as to textural, mineralogical, chemical composition and structure, and the presence or absence of inflow into the soil of ground water and its variability of the composition; 2) variability of the amount and form of radiation balance and of the atmospheric moisture cycle and the variability of the position of the soil in the relief; and 3) differences in species and number of living organisms (higher and lower) and their biological characteristics.

As a result of all these different factors and conditions in soil formation, the single soil-forming process, in which the biological factor predominates, results in the formation of soils of different types. Moreover, the characteristics of the soils being formed may depend in the same degree on the characteristics of any factor or condition in soil formation. Herein lies the parity of factors in soil formation noted by Dokuchayev, which does not in any way contradict the predominance of the biological factor in the actual realization of the soil-forming process.

From this point of view the geographical distribution of soils, too, if we bear in mind the *complete range of their diversity all over the Earth*, depends likewise on all the factors and conditions in soil formation. If we restrict ourselves, however, to the most widespread groups of soil, which are comparatively few, their geographical distribution will be found to depend mainly on climate—owing to the fact that, first, the number of forms (groups) of each factor in soil formation is not great, and secondly the combination of these forms (groups) and their interchange in an area is governed by the law of zonality, i.e. is determined by the climate, as Dokuchayev made clear when he wrote: "We all know that the *plant and animal world*, and to some extent the *mineral kingdom* (at least in their superficial formations) change in a strictly determined order from the equator to the north and south poles according to zonal, latitudinal belts and climate" (9, p. 382). In addition to this, however, Dokuchayev clearly conceived that "the exquisite picture of horizontal zones is a *system*, or, if you wish, a *law*" (9, p. 389), i.e. that the zonal distribution of soils is one of the laws governing their distribution, but by no means the only one.

All that we have said has been, by definition, concerned with natural soil formation and the participation of natural factors in it. We shall conclude with the part played by man in soil formation.

As is well known, at a specific stage in the development of human society the soil becomes an object of work and a means of production. Man begins to interfere actively in the process of soil formation, whereupon his agricultural activity becomes a factor in it.

This factor in soil formation, however, although usually combined with natural factors, is a factor of quite an individual kind. This is determined by the fact that the influence of man on the soil-forming process can from its very nature be clearly distinguished from the influence of natural factors, and may, according to its intensity, considerably exceed it. Man may influence soil formation not only by the immediate effect of his work on the soil, but also indirectly, by acting on it through natural factors. Examples of the direct influence of man on the process of soil formation are mechanical soil-cultivation, irrigation, drainage, the application of fertilizers and soil-improving substances, leveling, etc.

The indirect participation of man occurs most often through his influence on the biological factor. A simple instance is the felling of trees, which results in a change of vegetation. In using the soil for agriculture, man at times completely destroys higher vegetation (bare fallow) or establishes pure stands of various crops not specific to a given soil in its natural state. The grazing of a large head of livestock, again, is a substantial interference in the process of soil formation.

The influence of man on the process of soil formation is usually exerted in various forms simultaneously. With the development of social conditions, science and techniques, the part played by man in soil-formation increases and takes on new forms, becoming more and more purposeful all the time.

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DOKUCHAYEV'S DOCTRINE ON FACTORS IN SOIL FORMATION AS A BASIS FOR THE COMPARATIVE GEOGRAPHICAL METHOD OF SOIL INVESTIGATION[1]

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THE knowledge of interrelationship between soils and natural substances and the phenomena which Dokuchayev rightly termed "factors," —fundamental causes of soil formation—are important. In this connection the points made by Professor L. I. Prasolov should not be overlooked. He repeatedly stressed in his work that soil science—geographical research and its main result—the soil map of a given locality—should provide a picture of objective soil characteristic changes in the area, a picture of the soil cover of a given locality, and be a means of apprehending the laws governing soil formation and distribution in relation to the combination of various natural phenomena. "The geographical analysis of the phenomena of soil formation by means of soil profiles and maps", wrote Prasolov, "not only gives an account of the area occupied by different soils but also elucidates the causative links between these phenomena" (2, p. 10).

Prasolov understood the importance of experimental studies of soil formation processes including research on the balance of substances formed and translocated in the soil, and he always favored development of experimental studies of soil processes in the field. He also emphasized that "... taking into account soils and other factors in a geographical cross-section ..., i.e. in a given area ... we can utilize the experiment of nature itself in its endless replication, in its enormous masses—that is, on a scale unapproachable in our experiments" (3, p. 38).

This indicates the importance of the comparative geographical method of studying soil cover. However, one should bear in mind that it is necessary when using this method to begin with correct concepts on the nature of the soil-forming process and the part played by natural phenomena in its development.

At the same time we must admit that the principal foundations of the method of analysis of the interrelationship of the soil and soil-forming factors are almost completely ignored in our textbooks on soil research. This problem has many aspects and it is not possible to attempt an elucidation of it all from sides. Among the problems confronting the investigator as he attempts to clarify the laws governing soil formation and distribution, the following are in the forefront:

1) establishing the nature of the effect of various natural substances and phenomena on the soil;

2) generally evaluating the importance of various natural phenomena in soil formation and in particular, the changes in the soil characteristics of an area;

3) clarifying the dynamics of the interaction between factors and soil during the development of soil cover;

4) establishing the relation of various soil properties to the action of specific factors in soil formation.

The solution of the last three problems on the basis of research on soils in their natural setting becomes difficult for the geographer-soil scientist because the interrelationships between soil and elements of the geographical complex change with various combinations of soil formation factors. We should note that a change in any natural factor in soil formation inevitably results in change in other factors acting jointly on the soil, and that the extent of the effect of each factor varies as a result of various combinations of other factors.

Turning to the first problem, we should stress the necessity of distinguishing between direct and indirect effect of natural factors on the soil process.

According to existing concepts we should regard as direct any effect of a given factor in soil formation that directly alters the balance of energy or matter or the dynamics of the cycle of substances which constitutes the essence of soil formation. In accordance with this, indirect effect of a factor in soil formation is marked by a similar change of balance or of the dynamics of the cyclic processes affecting the soil, but only through the agency of change in the effect of other factors.

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[1] Presented at the 5th Commission of the Moscow branch of All-Union Soil Science Society.

Living organisms, parent materials, atmospheric processes and solar energy exert both direct and indirect effects on the soil. In the first case they act as factors, while in the second they can be considered as conditions of soil formation. In various instances the natural phenomena mentioned can, while remaining factors, be conditions of soil formation to a greater or lesser extent.

Among the factors of soil formation mentioned by Dokuchayev, the relief should be regarded as the least; it always plays a passive, although considerable, part and its significance is similar to that of the geographical situation of a given soil.

It is unnecessary to discuss in greater detail the question of the importance of dividing the effect of natural substances and phenomena on soils into direct and indirect. As a result of indirect influence, e.g. the mutual effect of climate, organisms, parent materials and relief, together with their interaction (at the same time) with the soil, interdependent combinations of natural substances and phenomena gradually arise to guide soil formation in a definite direction (in other words, the isolation of specific "groups of soil origin", in the words of Sibirtsev (5), gradually takes place in this way).

In the second problem—the importance of various natural phenomena in soil formation in general and changes of soil characteristics in a given area—we should stress the outstanding importance of the biological factor in both soil formation and in the subsequent continuous course of the soil process.

We frequently hear asserted that vegetation, microorganisms and the larger animals associated with the soil, penetrating the solum and to some extent even fusing inseparably with it, should be considered as the fundamental or dominant factor in soil formation, while the other components of natural complexes are of secondary importance. Such an assertion requires clarification.

The whole complex of living organisms associated with the soil should be considered as the immediate fundamental cause, and consequently the dominant factor, in soil formation. This is not at all at variance with the fact that organisms penetrating the depths of the soil constitute an inseparable part of its mass. These organisms however do not lose their individual characteristics, and the mass surrounding them continues to be their habitat.

The predominant importance of organisms in the soil process is determined by the fact that not a single soil can be formed without the action of living beings. We know that soil is not formed without participation of the other natural phenomena mentioned by Dokuchayev. But organisms are the most direct and active soil-formers, concentrating and transforming energy, and are extremely active transformers of the direct action of other natural factors on the soil. Thus the biological factor not only is an active soil-former but can also in specific cases exert a very strong indirect influence on the translocation and transformation of substances in the soil. In this connection the diversity of the effects which can be exerted on the soil by the complex of organisms associated with it should be emphasized.

While conceding the predominant importance of organisms in soil formation, on the basis of what has just been said, we are strongly opposed to underestimating the importance of other natural factors affecting the soil. It must be granted that such phenomena as solar energy, atmospheric processes and characteristics of parent material, exert an indirect and a direct effect on the soil formation process, and should not be regarded merely as conditions of the activity of organisms.

This is confirmed by the fact that organisms must adapt themselves gradually to the soil and struggle with their unfavorable conditions during soil formation. Thus, moments of adaptation by microorganisms alternate with periods of their active transformation of soil.

The importance of diametrically opposed processes depending on periodical and non-periodical changes in the intensity of the effect of solar energy and atmospheric agents in soil formation is well known. These changes produce a definite rhythm of soil formation to which living organisms must adapt; these appear as a stimulant to their natural evolution and consequently to the evolution of their effect on the soil.

If we conceded that organisms are the only factor in soil formation and regarded everything else as conditions of their activity, we must classify the elementary processes constituting soil formation, i.e. the phenomena which occur in the solum, not only as biological, physical, chemical etc., but also as strictly soil-forming and non-soil-

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forming. What should they be termed? We should then have to regard that ascending currents, evaporation and translocation of mobile substances in the soil as well as a number of other phenomena produced by forces of non-biological origin are not elements in soil formation. Would it not be more correct to concede that soil formation is distinguished from other natural processes by the fact that phenomena of a different nature are especially closely interwoven with it?

Besides generally establishing the dominant importance of the biological factor in soil formation, we should stress the need for elucidating the various changes in soil cover in a given area, noting the role of other factors and conditions in soil formation at different times. We know that although vegetation and the complex of living organisms are a condition of the most fundamental constituent of soil formation—the biological cycle—the distribution of plants and the nature of their activity depend on other factors—the relief and history of its development, the composition of parent materials and climatic changes. Therefore, the changes in soils observed by us in a given area depend on the relief and parent materials as much as on the action of organisms even if these changes are produced chiefly by differences in the biological cycle. Hence the need in soil science-geographical research not only to establish the dominant factor in soil formation—the main cause of the transformations and translocations of substances occurring in the solum—but also to distinguish the determining conditions, which may be changes in the relief or in the soil-forming parent materials or in the regime of ground waters, as the case may be. Thus alteration in the relief, for instance, may be shown mainly through change in the vegetation cover (and the microorganisms associated with it). Essential alteration in the effect of other factors on the soil begin only with a further increase in the degree of alteration (the depth of a hollow, the steepness or exposure of a slope etc.).

We can, consequently, regard this first stage of alteration in the relief as a determining condition in soil formation, while the vegetation cover of the whole area remains the dominant soil-former. At the second stage of alteration in the relief (from the viewpoint of change of soil characteristics) the effect of incoming ground waters or of the hydrothermal regime of the layer of air near the ground will come to the forefront. The relief in this area will remain a determining factor in soil formation, too. Similarly, it is possible to establish different points in the action of composition change and characteristics of soil-forming and underlying parent materials. To a definite point this action may be made evident chiefly through change in the specificity of the biological cycle (for instance, when carbonates appear in the soil-forming parent material at a depth of 1.5 to 2.0 m—a level reached only by separate roots of deep-rooted plants), and then may act directly through a change in the mineral composition of the soil mass and soil solution.

Here at the first stage of change in the parent material, its role will also be determined mainly by conditions of soil formation; the vegetation cover will remain the dominant factor, and the more or less intensive biogenous accumulation of soil-formation products in the upper soil horizon will depend on it. But even in the area where change in composition and characteristics of the parent material approaches the surface, it becomes not only a determining condition but also a new, very important directly-acting factor of change in soil formation.

Let us turn to the third problem—the dynamics of the interaction of factors during soil cover development. The change of effect of any factor in relation to the combination of all the other elements in the geographical complex is inseparably linked with this problem.

We have pointed out that the second most important characteristic of the effect of the biological factor on the soil is the many-sidedness of its influence—its ability to act on the soil in different ways, depending on environmental conditions. At the same time our soil investigations show that in the places where the nature of the effect of any non-biological factors in soil formation acquire a special intensity, the direct effect of the biological factor may become secondary. An example of this is the formation of numerous salinized soils, whose characteristics depend very little on the effect of vegetation and microorganisms; this formation is connected with processes of a purely physical and physico-chemical order. The role of the biological factor does not disappear, it simply becomes more indirect—expressed through other factors (for instance, the hydrothermal regime of the air above the soil surface and so forth).

Another example of soil formation in which vegetation plays only a small part is the formation of arctic soils with clearly expressed translocation of substances through freezing, with symptoms of the effect of periodic seasonal freezing and thawing of water within the surface layer, with accumulation of salts near the surface, and so on. In all these cases any of the natural factors except the biological—climate, characteristics of the parent material, composition and depth of ground waters—may acquire an intensity in which the direct effect of vegetation and of other organisms on the soil is sharply reduced.

This explains the previous statement that the effect of each factor on soil is shown in differing degrees under various geographical conditions—that it may produce more contrasted and less contrasted changes in soil characteristics. Thus, for instance, a change in the gradient of a surface or in the exposure of a slope to a given value in one locality may cause only a slight quantitative variation in individual soil characteristics (for instance in the degree of carbonate leaching, in the reaction of soil solution at the soil surface, in humus content etc.), while in another place it will produce new qualitative soil characteristics and will be reflected in change in its typical characteristics. Soil-forming living organisms, especially vegetation and microorganisms, are at the basis of these variations in effect of a single factor on soil under different geographical conditions.

We must take into consideration that sharp changes in soil properties during slight changes of effect of various factors or conditions in soil formation can be observed when these changes occur in a range close to the critical range for activity of specific groupings of living organisms associated with the soil. Such changes usually occur during fluctuations in soil moisture either near the lower limit of water availability or near the bog-formation point; naurally this fluctuation takes many forms. These changes may have various durations, may occur earlier or later during the vegetation period, may coincide with definite points in the temperature regime and may be associated with both atmospheric climate and local geomorphological conditions. Specific changes in plant groupings, moreover, producing adaptive functions of a different kind and acting differently on the soil, correspond to variations in the hydrothermal regime.

The salinization of ground waters occurring near the surface or the presence of easily soluble salts in the layers of parent material occurring near the surface are equally important in the alteration of soil cover.

Sometimes, on very weakly or very slightly weathered rocks an essential role in the clearly expressed spatial variability of soils may be played by a low concentration of available mineral elements necessary for plant cover and microorganisms. In such places slight local changes in rock composition or in the relief may be reflected in very considerable changes in soil properties.

Highly contrasted combinations of soils occur somewhat in greatly broken mountainous country with slopes of different exposure and, especially, in specific elevated belts such as those where the hydrothermal regime approaches the critical point for various large plant groupings. Again, changes in exposure to the sun (in the forest steppe belt) or in exposure to wind (in the forest tundra belt) may be very important (6). In all these cases the most substantial differences in soil characteristics depend on changes in plant cover and, associated with it, of the nature and intensity of plant residue decomposition.

Very striking examples of change in the effect of plant cover on soil formation can be seen in descriptions of the process of soil-complex formation in southeast European Russia (1). Ivanova and Fridland stress that vegetation is the factor determining these complexes. "Complexes arise" they write "where the most complicated coenosis-habitats are produced, preventing the emergence of homogeneous well-developed plant cover."

From this, and from subsequent descriptions of the authors, we see that the role of plant cover can be dominant during the process of complex-formation, but the first impulse towards the emergence of heterogeneous plant cover—the formation of complicated coenosis-habitats, was given by other factors: by the composition and nature of soil-forming and underlying parent materials or by rudiments of the microrelief. Thus here, as in the formation of soil combinations, the determining role is not played by the biological factor, whose role increases subsequently when a soil profile develops as a result of vegetation. But at this stage during the formation and development of the complex, moments of direct effect of plant groupings combine (or alternate) with moments of weakening of their relative role and of adaptation to change in soil properties.

The studies of these authors on the evolution of soil complexes in the dry steppe zone are very important. From a study of the process of change in soil cover on the surface of the primary plain emerging from the water—on the river bottom-land or on the shore of a lake which is drying out, four main stages in the formation of complexes of vegetation and soils can be established: meadow, solonchak, meadow-steppe and steppe. The relief development of a given surface and the change of water régime associated with it are a determining factor in the interchange of these stages. Depending on the rate or rise of the bottom-land terrace above the water level, and on change in the régime of floods and lowering of the ground water level, successive changes in vegetation and all the cycles of soil variation occur. Associated with this phenomenon is the formation of complexes, which, however, are governed by their own laws at each distinct stage of development.

The first stage—the meadow stage—is marked by the greatest homogeneity of vegetation and soil cover. The soil cover is particularly homogeneous at this stage, whereas the vegetation may be markedly differentiated in places. Homogeneity of soil cover on recent alluvial plains depends, however, on uniformity of alluvial deposits —parent materials—and on the water and salt regimes which are being established. In most cases, owing to comparatively intensive water-exchange resulting from periodical floods and movement of ground waters, relatively favorable conditions are produced on meadow terraces for the development of vegetation, and critical points in relation to moisture or salt concentration do not arise. Naturally, however, conditions of water supply and of the salt regime may change in various parts of the bottom-land surface; this determines the emergence of plant groupings of somewhat different composition, and variegation of vegetation is observed. This variegation is only slightly reflected in soils, usually in distinct, comparatively variable characteristics.

The second stage—the solonchak stage—is characterized by a weakening of the indirect effect of vegetation on soil formation, by considerable differentiation in the amount of vegetation cover and by clearly marked spottiness of soil cover. This spottiness results mainly from the original bottom-land-accumulative microrelief, and is the starting point of the development, complexity and emergence of the secondary microrelief. The role of vegetation, moreover, becomes mainly indirect: it changes the conditions of water supply and salinization. These changes may, however, be more important during the further evolution of the complex.

The third stage—the meadow-steppe stage—is marked by the greatest heterogeneity of vegetation and soil cover; this heterogeneity becomes typically complex: the boundaries between areas with different soil structures become clearly expressed, the soil acquires relatively stable and strongly contrasted characteristics, and the area of spreading of homogeneous soils is contrasted. At this stage the solum is moistened by atmospheric water, although the connection with ground water is still not completely broken. Here the sharp differences in soil characteristics and structure result mainly from the different course of the desalinization-salinization process on various areas of the surface; this is caused by the different amount of salts in the soil, accumulated during the preceding stage of soil formation, by heterogeneity of salt composition of ground waters, by development of the microrelief (deposition of a second suffusion-sedimentary microrelief on the primary bottom-land-accumulative relief) and a corresponding distribution of vegetation strongly affecting the degree and nature of soil moistening.

The role of the biological factor increases at this stage: during its initial phase the action of vegetation cover on the hydrothermal regime—and consequently on the salt regime—of soils is still decisive, but subsequently the direct effect of the biological cycle of carbon compounds, mineral elements and nitrogen on soil structure and properties gradually increases.

The fourth and final stage of the series—the steppe stage—is characterized generally by a decrease in heterogeneity of vegetation and soil cover, particularly in comparison with the preceding stage. At this stage of development new forms of heterogeneity of soil-vegetation cover emerge, whose formation, however, is somewhat predetermined by the previous history of the formation of the surface. These new vegetation and soil complexes—already steppe-complexes—not connected with ground waters, are formed with a deepening of the level of permanent and temporary water flow and with the formation of new forms of erosion relief. As a result, on slopes of elevations and in depressions adjoining gullies, residual salt accumulations, whose level is reached by surface waters, approach the surface. Thus, mobilization of salts, redistribution of vegetation and the formation of new complexes take place.

Steppe complexes, according to the description of various authors (4, 1), are formed in various ways, but most can be regarded as reflecting previous history of the formation of the dry steppe surface on the site of the meadow plain.

The vegetation at this stage more or less repeats in a new setting its role in complex-formation, as revealed at earlier stages in change of the relief and of the water-salt regime of the alluvial plain. Here we see that the first impulses towards redistribution of vegetation and differentiation of soil formation are determined by the development of the relief and by rock composition (or early soils). The direction taken by this process is closely associated with characteristics inherited by a given surface from the previous stage. The further formation of the steppe complexes themselves is strongly influenced by vegetation, which promotes local changes in the hydrothermal regime but is continually in complex interaction with processes of translocation of water and salts resulting from climatic regime, character of the surface and composition of parent materials.

This role of vegetation, directed towards the differentiation of soil cover, should however be regarded as only a specific point in the history of the soil cover of early-alluvial plain. A more general and characteristic trend of the effect of the biological factor at this stage is a direct action on soil in the direction of desalinization, desolonetization and, finally, transformation of the area into a comparatively homogeneous expanse with the zonal soil group predominating.

The examples quoted show that the role of the biological factor in the formation of soil properties and structure, and in the spatial variability of soil cover, changes during interaction with other soil-formation factors in the course of time. The character of the effect of this factor on soil formation changes also. Naturally it is very difficult to draw a line between direct and indirect effect in such a complex and many-sided phenomenon as the effect of vegetation and other organisms on soil.

During the initial stages of soil formation the trend of soil development is not always determined by the biological factor, and later its active role as the dominant soil-former can temporarily be diminished under pressure from other natural phenomena.

The most pronounced variegation of soil cover —its complexity, which at times produces conditions close to the critical for activity of different groups of organisms—is characteristic of specific and (in the examples considered by us) relatively early stages in the formation of soil cover of primary plains with a general trend in relief development towards a lowering of erosion level.

According to our observations in the northwest and center of the forest zone of European Russia, the phenomenon of soil spottiness is also associated with comparative recentness of soil cover and soil-forming rocks. With this trend towards breaking up in the development of the relief, this phenomenon diminishes in the area of development of the earlier relief and of more weathered parent material. This is easily understood, as under these conditions the action of vegetation must eventually level these small spatial differences in individual soil properties, which result from local characteristics of interaction between the biological factor and the parent material.

Thus, during formation of soil cover the role of the biological factor changes both in its intrinsic character (in the relationship of the various aspects of its action on soil) and in the characteristics of its interaction with other factors in soil formation, and under certain conditions it temporarily falls back into second place. Variegation of soil cover may become particularly strong at these precise moments.

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THE NATURE AND FACTORS OF SOIL FORMATION[1]

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FROM the standpoint of modern soil science, soils appear to be the function of five essential soil forming factors: parent material, relief, climate, organisms, and time (6), where biological factors—organisms, are of foremost significance (2). The leading role of the biological factor remains vague and often appears declarative, particularly in cases where changes in soils are obviously caused by changes in relief, composition of the parent material, climate, and other elements of inorganic nature.

While the theory of factors as such (in our opinion) played a highly progressive role in the Dokuchayev period of formation and development of soil genesis, it does not keep up with current development of the sciences and needs revision.

There emerges from the scientific achievements of the sixty-year post-Dokuchayev period a logical and urgent need for distinguishing between concepts of a biological nature as the main cause and a direct driving force in soil formation, and the factors of inert matter as conditions for development of this process. While a direct approach to this point of view is found in N. M. Sibirtsev (23), many principal ideas on soil formation are found in the work of V. R. Vil'yams, V. I. Vernadskiy, and B. B. Polynov. Fragmentary information may also be found in the literature of a number of contemporary authors, such as Yarkov (32), Tyurin (28–31), Gorshenin (5)[2], Gerasimov (4), Rozov (23), and others. Recently, Papazov (20), attempted to verify its validity in the light of Vil'yams' teaching.

In our paper an attempt shall be made to substantiate and develop this point of view, which in part has already been expressed in some of our earlier work (14, 15, 16, 18, 19).

First, we must note the meaning of the word "factor." Factor (from the Latin word *facere* means "to make") is the driving force, the cause of some process or phenomenon. It was exactly in this meaning that the word "factors" was used by V. V. Dokuchayev for determination of the driving natural forces, the causes of soil formation.

The idea began to develop with Dokuchayev and Sibirtsev that organisms and parent materials, which form the soil mass, are the real factors of soil formation, whereas climate and topography are the conditions for this process (4 and others). Time is particularly singled out as a general condition for the existence of matter. Other workers (22) expand the concept of factors, understanding it to be the phenomena which directly influence the soil, both in substance and energy. From that point of view, organisms, parent material, and climate come under the category of natural factors.

In most—if not in all modern works—the terms "factors" and "conditions" are used synonymously. For example, one speaks of the "hydrothermic factor" and "hydrothermic conditions", "bioclimatic factor" and "bioclimatic conditions", "parent material factor" and "parent material conditions." The following citation from the recent work of Gerasimov (3) illustrates this point: "The modern combination of soil-forming factors or, the definite complex of natural conditions, which influence the formation of a genetic soil group, were shaped by prolonged historical development." There is lack of clarity on this important subject, and thus it is of concern to every soil scientist.

For example, when factors affecting the life of plants or other organisms are discussed, it becomes clear that they affect an organism and are the indispensable external conditions for its survival. Relative to soil-forming factors, which are widely different in nature (organisms, parent materials, relief, climate, and time) it remains unclear upon what exactly they act. On parent material? If so, parent material then would not be a factor, but rather an object on which other factors exert their influence. On soil? Soil, how-ver, does not precede the soil-forming process, e nature of which we would now like to scrunize.

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[1] Presented before the 5th commission of the Moscow Division of the All-Union Society of Soil Scientists.

[2] We are pleased to note the close agreement of our point of view with that of K. P. Gorshenin: "Generally, it is perhaps more correct to consider organisms not only the fundamental factor, but the sole factor in soil formation, and to place the other factors of V. V. Dokuchayev in the category of soil-forming conditions."

The view that soils form as a result of the comined effects of all soil-forming factors can hardly e considered clear and correct in the light of their teraction. Herein lies the first weak point of the ctor theory. If the soil were looked upon as a irror of the natural landscape, it would be imossible to examine it from the geographical oint of view alone without thoroughly undertanding the direct causes and internal nature of s very formation.

The second weak point of the theory of factors esides in the following. Factors, climate, parent aterial, relief, organisms, and not to speak of me, differing materially and energetically, could ot have the same action. It is particularly eroneous to equate to one and the same factorial tegory the action of the living organisms (even s the principal factor) on the one hand, and the lements of inorganic nature on the other. Living henomena and their existence and role of life in ese or other processes are so different from the ppearance and role of the inert matter that it is npossible to even visualize their being equal. he surrounding inert matter always remains nly the medium, the environment, for the life rocesses and is not equal to the effect of life.

The factor theory does not explain the direct auses of soil formation. It has to a certain extent ontemplative or inadequate analytical character. ccording to this theory soils are apparently ormed because of the existence and interaction n nature of certain soil-forming agents deterined by Dokuchayev. Specific correlation of eir actions at various points of the earth surface pparently determines the natural variety of oils. The factor-genetic soil classifications (9) for xample, appear to be a reflection of this point of iew.

However, from the standpoint of the cause of oil formation, there is a profound material diference between organisms, parent material, reief, and climate. Parent material, relief, or imate alone or combined cannot form soils and re not the causes of their formation. The unique nd immediate cause for the rise and developent of the soil cover of our planet is the existence the biosphere of living autotrophic organisms—e green plants, which cannot exist without the ineral elements of the earth crust and are therefore well-rooted in its top layer.[3] In the course of utilizing the earth surface as the source of mineral nutrition and water, they live together with microorganisms and form the vital substrate, the soil complex. All elements of the physiographic environment participate materially and energetically in this process. The soil is the outgrowth of the mineral nutrition of plants, the autotrophic formation of organic matter and its transformation (including mineralization) by microorganisms. Such is the common cause and nature of the soil-forming process on the earth surface.

Soil formation takes place under various physiographic conditions—climatic, geologic, geomorphologic, hydrogeologic, etc., which change not only the plant-microbial associations, but also conditions of their actions upon the mineral cover of the earth causing enormous and constant change of soils in nature. This is not exclusive and peculiar to the soil cover. There is a geography not only of soils, but also of plants, animals, and even man, particularly at the lower levels of his social development.

It is noteworthy that in modern soil science the significance of the individual soil-forming factors, in most cases, is interpreted only in relation to the natural variation of soils, but is not strictly related to a definition of the concept of soil. When the alteration of the soil cover is brought about by the change of vegetation, then the leading role of the biological factor is undisputably recognized. When, for example, the modification of soil is affected by a sudden change in relief, composition of parent material, and other elements of inorganic nature, then the problem becomes complicated and, in such cases, the recognition of the leading role of abiotic factors becomes imperative.

However, geological, climatic, and other conditions of an inorganic nature can virtually bring soil formation to a standstill, as is typical in solonchak, in dry desert sands, etc. But, does this mean that under the given circumstances, the geological and climatic factors are of primary, and the biological factors of secondary importance for soil formation? No, it simply means that by the suppression of the biological factor, the formation of soil is also suppressed.

The degree to which the geological and climatic factors directly effecting the uppermost layer of the earth crust is greater than the cumulative influence of the biological factor—manifested as soil formation—to the same degree this layer loses soil characteristics and acquires properties of a geological formation. In relation to soils, conditions which inhibit or favor growth of vegetation are the same.

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[3] Hydrophytes also utilize salts of earth origin.

The fact that soils are formed in closest material contact with elements of surrounding nonliving matter (not like living organisms which are materially separated from the environment by virtue of the closed shape of their bodies) hampers the distinguishing of true soil formation from other accompanying side-processes, such as geological salinization of the locality. Whereas in biology, at times, organisms are studied incorrectly—completely divorced from the environment, in soil science, on the other hand, the elements of the environment, the conditions, cannot be divorced from the very nature of the biological process. Accordingly, when the soil formation is suppressed by conditions unfavorable for life (tundra, desert, and saline areas) then the manifestation of such conditions is accepted as the result of the soil formation, and in the main it apparently becomes not biological, but climatic, geological, and so on. With this understanding of soil formation, it is impossible to discuss any definition of this process. What must be discussed is that soil formation is a complex of processes, and its characteristics are dependent upon the prevailing actions on the surface of the soil, of either biological, climatic, or geological factors.

It is in order to point out the very significant difference between the effect of organisms on soil formation on the one hand, and all other Dokuchayev factors on the other. Only that agent can be called soil forming which initiates this process always and in direct relationship to the degree of its activity. Of all the Dokuchayev soil-forming factors only organisms satisfy this requirement. According to the degree of development, soils are in general mirror images of the vegetative cover that forms them. Tremendously developed soils are seen in subtropical regions with a high productivity of vegetative growth, in shallow soils under lichens and other vegetation in the arctic and extremely arid regions.

What then can be said in this respect about the effects of climate, parent material, and relief? It is well-known that excess of water, as well as the lack of it, suppresses soil formation. Excessively mineralized—salinized ground, as well as a poor quartz sand, are unfavorable to soil formation Pronounced depressions become filled with water and the high mountain peaks remain under permanent snow cover. Thus, only the activity of organisms is directly related to the degree of development of the soil cover. However, all the other Dokuchayev factors—climate, parent material, and relief are most favorable for soil formation when in the optimum of their expression properties, or combinations but unfavorable and even destructive when in the maximum or minimum. This shows that they are only the soil-forming conditions, and that this process is biological in nature.

In accordance with this understanding of the soil-forming process, we should like to offer the following short definition.

The soil-forming process is a biologically integrated, continuous, dynamic, natural historic process in which the top layer of the earth's crust is actively utilized and transformed by organisms, chiefly by higher and lower plants,[4] with the participation and influence thereon of all the elements of the physiographic environment, and under the conditions of cultivation and economic activity of man.

This definition includes all aspects of the soil-forming process. It answers such questions as: What is formed (soil), what forms it (organisms), from what is it formed (from products of activity of organisms and the top layer of the earth crust), how is it formed (by a two-way process—biological utilization and transformation), under what conditions (under diverse conditions of the physiographic medium), what is the nature of this process (integrated biological), what is the character of this process with respect to time (continuous, dynamic, and historical–natural).

Soil is formed only by those specific soil organisms: plants, microorganisms, protozoa, insects, small invertebrates, whose metabolic processes are indispensable The role of other organisms, such as higher animals, is atypical of this process, scattered, and passive. It does not bear the properties of a two-way process, that is the concomitant utilization and formation of soil. Accordingly, the effects that higher animals ay exert on soil genesis may be related only to he conditions of this process.

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[4] It is self-evident that transformation is not affected only by living organisms but also by the products of their activity.

Burrowing animals mix the soil but do not paricipate in the specific process of its creation. If, or example, in the steppe zone, the burrowing nimals were to be destroyed, the formation of hernozem by the steppe vegetation would not e interrupted. It would be interrupted, however, y destroying the vegetation while leaving the nimals.

Soil is primarily a necessary substrate (and at he same time the creation) of higher forms of hlorophyllic plants, which synthesize organic atter from atmospheric and earth mineral eleents, but not of animals which use the products f this synthesis for their metabolic activities. ccordingly, the higher forms of animals have no irect need for soil, and, therefore, do not form it.

Man himself is very much aware of the soil. irectly, he does not need it for his existence ither. He uses and improves it in order to obtain igh crop yields, that is, the indispensable prodcts are crop-growing (also forestry), which are ed to livestock. The agricultural activity of man s a purposeful means of modifying the conditions nd, accordingly, the course of soil formation, ut not its nature which is inseparably linked o the activity of soil organisms. Similarly, we annot, for example, change photosynthesis, which s a process deeply imbedded in the biological ature of a vegetative organism; we can only mprove the beneficial activity of organisms, that s, enlarge its scale in a given area and prouctivity.

In essence soil formation is a process consisting f reciprocal cause and effect action of specific rganisms (chiefly higher and lower forms of lants) on the top layer of the earth's crust—use f that layer as a source of mineral nutrition and ater supply (cause) and transformation (effect).[5] he result of this process is the development of he soil's most important qualitative property—ertility.

The source of soil fertility proper, that is, inrganic elements, is parent material (soil obtains ater and nitrogen from the atmosphere). The evelopment and building of soil fertility is the esult of the activity of organisms. Fertile soil ust possess mainly an abundant supply of available nutrients, which must be resistant to leaching, and should have sufficient water-holding capacity. First there is the concentration of dispersed inorganic elements of the parent material and the fixation of atmospheric nitrogen by organisms. The second and third are the accumulation in soils of the newly-formed bio-entities, humus and clay, respectively, which possess high adsorption and water-holding capacity. Thus, chemical, physicochemical, and physical properties of soils are basically of biological origin.

The essence of soil formation may be considered as being the result of vital activity, propagation and continuous change of generations of organisms, primarily those of higher and lower forms of plants. Soil is the result of the life and death of generations of organisms, from which life is constantly newly regenerated. This is a great example of "negation of negation" in nature.

Soil formation is organically tightly bound with photosynthesis. In the natural conditions (on land) they cannot exist independently of each other. These are two interrelated sides of the same biological process, the vital activity of higher and lower forms of plants. This is why soil science is closely related to agriculture and plant physiology. The processes of photosynthesis and soil formation are bound by the continuous metabolism of energy. As a result of photosynthesis soil secures precious energy-rich material—plant residues—and the atmosphere replenishes its oxygen, which enters the soil as a gas and is dissolved in the rain. As a result of soil formation, carbon dioxide, which is indispensable for the continuation of photosynthesis, and with it for life, is returned to the atmosphere. It follows then, that the biological nature of soil formation has very deep-rooted bonds and consequences on a planetary scale. Is this perhaps insufficient to set apart this essence from all other nonbiological soil-forming conditions?

The soil. In accordance with the foregoing definition of the soil-forming process, soil is the more or less powerful and fertile uppermost layer of the earth crust, which is being actively utilized and acted upon by organisms (mainly plants and microorganisms) under the material and energetic participation of all the elements of the physiographic environment, and under the conditions of cultivation, the management activity of man.

The systematic units of soil are natural, dynamic forms of the manifestation or development of the soil-forming process under different conditions of the physiographic environment and economic activity of man. They have distinct qualitative and quantitative characteristics, which are manifested through the level and quality of soil productivity. It would be impossible to discuss this problem here.

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[5] Transformation of matter during its utilizaion is a law which has a wide prevalent distribuion in nature—also the basis of man's activity.

Factors as conditions of soil formation. In respect to the previous presented concepts, we understand by soil-forming factors (1) the individual, intertwined, and interrelated elements (conditions) of the physiographic environment and economic activites of man: climate, parent materials,[6] relief, hydrogeologic conditions, man's agricultural practices, and many others, and (2) the more specific conditions which affect not only the composition and quality of soil-forming organisms but also the soil-forming process itself upon which they act.

Obviously, the influence of these conditions on soil formation is tremendous. Although their effects are reflected primarily upon the organisms, they concomitantly also affect soil formation. As a result of the effects of these conditions a definite physical and chemical medium is created from inert materials. Once the concept of the biological nature of soil formation is clearly distinguished from the conditions for this process, the cause of formation of any soil may be explained. On the other hand, the "theory of factors" imposes on us the artificial and virtually impossible responsibility of looking for the leading role of the biological factor in every single case of soil formation though it was necessary to overshadow the influence of all other factors. The "biological factor" exceeds the influence of all others in the sense that without it the soil cannot develop, just as there could not be life without a living organism. However, living organisms and soils are so dependent on environmental conditions that under certain circumstances the latter may completely inhibit the development of one or the other. The nature of the soil-forming process (a "biological factor" in modern terminology) cannot manifest itself outside the environmental conditions and depend on them. Thus, it appears that we are returning to Dokuchayev in the liberal interpretation of the effect on soil formation of climate, parent m terial, relief, etc., but on a new and clearer bas

It is impossible to compare the effect of the i ert matter upon the soil-forming conditions wi that upon the individual organisms. The orga isms are distinguished by relatively permane inherited characteristics, or at least to such a extent, that under similar intermediate cond tions this effect does not increase, such as th intermediate differentiation between spruce an pine, but it is characteristic of soil formation, t have infinite variation in transitional forms of soi From the point of view of soil formation, the e fect of geographical conditions upon the diffe entiation of plant-microbial combinations in th dry-land regions is important. As expressed b V. I. Vernadskiy, plant-microbial "living matter differing in species and chemical composition i encountered at various parts of the earth. Thi "living matter," together with the environmenta factors of inert matter, gives rise to various form of soil formation. The nature of soil formatio manifests itself in various forms depending upo the conditions of its development. While the grea development and "flourishing" of soils is ob served, for example, in the chernozem zone, th poor soil formation is noted in arctic Tundra an dry desert. How can one speak of the equivalenc of all the Dokuchayev soil-forming factors whe soils so strikingly depend upon living conditions

The importance of the individual conditions o soil formation is determined to a greater exten with respect to their overall biological significance. The conditions of the earth surface wer differentiated more by climatic conditions tha by the mineral nutrition of plants. Moreover climate appears to be an important, energy condition for soil formation. This is why the broa zonality of the soil cover stands out so distinctly

Since soil formation is a process of biologica transformation of the land surface of our planet the most harmonious picture of the zonal-climatic changes of soils is observed in regions o vast and relatively flat continental space. Larg water-filled depressions (seas, oceans) and mountains disturb this regularity and impose upon soil formation the influence of maritime and mountain climate. As one goes from northwest to southeast SSSR, for instance, it is then clearly evident that transformations of soils along this line have the character of a biological curve, in the center o which, under optimal relationships of temperatur and humidity, is located the higher soil group o his continent, the chernozem. A great many ery important and specific soil properties change xactly according to the geographical line, namely y the law of the biological curve, such as: the otal contents of humus, nitrogen, and humic cids (26, 27, 30), the complexity of the chemical tructure of humic matter (10, 11, 17), the depth f the soil profile, the reaction of the soil solution, he extent of the soil exchange capacity, and many others.

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[6] According to our point of view, it is clearly impossible to refer to "soil-forming rock". Organisms are the only ones which form soil. The parent material is merely transformed into soil. Dokuchayev used the term "parent material".

V. V. Dokuchayev, the great originator of the oil theory was right in attributing major signifiance to the climatic factor in natural soil varitions and considering it as a condition of soil ormation. It may be assumed that Dokuchayev id not single out the "biological factor" as a eparate category, relating to the very nature of oil formation,[7] because he approached the study f soils from a wider geological and geographical utlook rather than from a biological horizon, oncentrating heavily upon the phase of soil evelopment and paying attention to the entire et of visible "soil-forming factors." Also, he was he first in the history of sciences to discover the pecial and complicated branch of natural scinces—genetic soil science. One cannot expect hat, within the relatively short period of his acivity, in view of the almost complete absence at hat time of biological and biochemical informaion on soils, Dokuchayev understood the entire omplexity of soil formation.

In his later works (7, 8), Dokuchayev clearly xpressed his striving to understand thoroughly he close genetic association between the individal bodies and the natural "elements", particuarly between dead and live nature, the "plant, nimal, and mineral 'kingdoms', and to determine he position and role of soil in a system of 'a single, whole and indivisible' nature." He placed the enetic soil science "in the center of this new unerstanding of nature." This is understandable ecause among all the natural formations soil is o the greatest extent the synthesis of all natural henomena, including also specifically live and ead nature.

The complicated synthetic nature of the soil within which the dead and mineral masses domnate the living and organic masses, prevents ecognizing living portion to be more effective han dead portion as the driving force in soil ormation.

Now, after seventy-five years of existence of the Dokuchayev theory of soil-forming factors, it would be erroneous to continue to consider it the final instance in the development of the sciences. In the deadening of his own theory as a dogma, even Dokuchayev himself would not be interested. The words of Polynov (12) in the paper "V. V. Dokuchayev and Natural Science", dedicated to Dokuchayev's hundredth birthday and given at a joint meeting of the Division of Geological-Geographical and Biological Sciences of the Academy of Sciences, SSSR, are the example of a correct scientific attitude toward Dokuchayev's heritage.

". . . the purpose of a soil scientist of the Dokuchayev school can be understood in various ways. One can repeat exactly all the sayings of Dokuchayev, one can strictly follow the textbooks, not diverging from the old methods of describing soils and their analyses, in a word, one can preserve, in all its inviolability, alike the sacred relic, everything that we have today. To discharge this responsibility, similar to that of a museum or church guard, is undoubtedly an honored occupation, but it is hardly a productive one. However, one can also approach his problems in another way. One can depart from Dokuchayev's ideas, turn to new ideas, add and perfect methods, and widen the application of soil science to newly emerged sciences and practices. In other words, one can move forward steadily, and still remain a Dokuchayevian as long as one continues on the same path indicated by Dokuchayev himself."

It is worth mentioning, that the question of the biological nature and conditions of soil formation arose already at the very beginning of the development of soil science. After this article was put in print, we became aware of a now almost forgotten and never cited work by Rizpolozhenskii (21), a Kazan soil scientist, written about seventy years ago. Leaving aside all the erroneous and abstract theses of this author, which have already been criticized by Sibirtsev (24, 25), we find many of his thoughts and arguments (though expressed in a peculiar and old fashioned language) similar to ours. Rizpolozhenskii's error lies in the fact that he considered climate, parent material, and relief almost exclusively from the standpoint of their influence on soil-forming organisms, without taking into consideration their tremendous, though indirect effect upon the soil-forming process itself. The work of Rizpolozhenskii and the criticism of it by Sibirtsev, with which one cannot now agree in all respects, is of considerable interest and may warrant independent discussion.

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[7] However, he was close to it (cf. 30, 31).

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PROBLEMS IN GENESIS AND CLASSIFICATION OF THE TROPICAL SOILS OF CHINA[1]

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DESPITE extensive literature, the tropical soils are those least known to Soviet soil scientists both in genesis, and especially evolution, the product of plant activity and other factors. There are three reasons for this: an absence of these soils types in the USSR, the fact that our soil scientists are barely acquainted with them, and the fact that the soil scientists of various countries have studied these soils from a biased, chemical-mineralogical standpoint attempting to explain the processes and phases of the weathering of soil formation materials within the framework of the various physico-geographic conditions of the tropics.

While not contradicting the possibility of such study, it should be pointed out that within the framework of the study, from this standpoint, little attention is paid to the role played by the biological factors in the soil formation process—the reciprocal action with the abiotics determines the development of soils with the transformation processes of matter and energy peculiar only to them.

The isolation of the major groups of tropical soils: krasnozems, laterites, zheltozems, savannas, and others, is based on the various phases of the weathering of parent materials rather than on the soils properties formed on them. The weathering stages are still not clearly understood. Their formation is largely based on the differences in the parent materials, and not on the conversion of those factors which determine the composition of the weathered layer, its depth, and time of formation.

The Chinese soil scientists, for example, maintain that krasnozems are formed on the weathered parent materials, with the exception of the effusives, while laterites or lateritic krasnozems, depending upon the degree of occurrence and the presence or absence of podzolization, correspond to the basalts and similar rocks. Tropical zheltozems are usually considered to be intrazonal soil groups at a stage of weathering typical of krasnozems, but differing in the form of iron compounds present, i.e. oxides predominant in krasnozems, while hydrates predominante in zheltozems.

Gerasimov (1), considers allitization to be the fundamental process in tropical soil formation. The degree of allitization is displayed by the depth of the allitized stratum. In accordance with this he recognizes two basic soil groups: the lateritics and the laterites, the latter being characterized by a greater depth of the decomposed layer. Natural vegetation, according to Gerasimov, decreases soil aeration, causing the yellow color and podzolization in the surface horizons. The latter process appears to be superimposed upon laterization. As allitization increases, Gerasimov is inclined to recognize four stages of weathering which correspond to the following soil groups: yellow cinnamon-brown, lateritic, or krasnozem, yellow-lateritic, and lateritic proper.

Kovda (2), while accepting zheltozems, krasnozems, lateritic soils, and laterites (podzolized and non-podzolized) as basic soil groups of the tropical zone of China, points out that in order to better understand their nature, greater attention should be paid to the discovery of differences in these soils rather than to their similarities to soils of other countries and continents.

A brief survey of the literature and numerous works of foreign scientists shows that no understanding exists approaching unanimity of the importance of allitization in soil formation or the classification of basic soil groups on the basis of the processes occurring in them and determining their properties. There is especially little clarity in the understanding of krasnozems and laterites as independent soil groups and the significance of biological factors in their development. Several of these problems are the subject of the present study which is based on materials collected by us in the tropical sections of the Chinese provinces of Huandun and Yunnan.[2]

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[1] Delivered at the First Conference of Soil Scientists Delegates of the USSR, May 12–18, 958.

[2] The following persons participated in the study: Professors Khou Syu-ey and Khuan Zhen-tsay, and soil scientists Nyu Tszi-ven', O De-

TABLE 1

Mineral content of epiphyte plants and of their "baskets", % of absolutely dry matter[a]

Epiphytes	Ash	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	P_2O_5	K_2O	MnO	Total N	Other
Orchid—leaves	12.10	0.82	0.08	0.39	2.98	0.63	1.37	0.14	3.35	0.35	1.12	—
Orchid—rhizoids	18.50	0.88	0.09	1.34	4.22	0.52	0.79	0.13	1.13	0.20	1.66	—
Fern—branches	8.66	0.65	0.04	0.66	2.50	0.51	0.64	0.07	0.53	0.03	2.46	2.35
Upper part of "basket" of fern	10.46	1.07	0.08	0.23	1.40	0.18	0.73	0.12	0.75	0.02	0.92	4.54
Same, lower part	9.00	1.53	0.09	1.00	1.60	0.38	0.61	0.07	1.09	0.01	2.22	0.04

[a] Analyst: I. M. Rozanova

TABLE 2

Mineral content of leaves and needles of several tree species, % of absolutely dry matter[a]

Species	Ash	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	P_2O_5	K_2O	MnO	Total
Cnema	7.70	0.71	0.14	0.34	2.43	0.60	1.08	0.10	1.45	0.06	2.48
Dysoxylon	11.19	0.66	0.06	0.34	2.95	1.00	1.00	0.11	3.03	0.16	1.51
Epipremnum	15.64	0.54	0.09	0.35	4.87	1.31	0.96	0.19	3.37	0.20	1.94
Casuarina	5.78	2.27	0.10	0.23	1.40	0.18	0.73	0.12	0.75	0.02	0.92
Pinus (on schist)	3.80	0.77	0.09	0.46	0.84	0.26	0.83	0.26	0.36	0.05	1.70
Pinus (on granite)	1.43	0.13	0.04	0.24	0.27	0.18	0.32	0.25	0.40	0.03	1.41
Arundinaria	19.85	14.95	0.07	0.09	0.61	0.33	1.37	0.28	1.33	—	2.02
Mangroves											
Brugiera conjgata	10.31	0.19	0.02	0.09	2.48	0.53	1.23	0.24	1.42	0.02	1.71
Aerosticheum auveum	6.71	2.16	0.06	0.42	0.37	0.63	1.13	0.25	1.30	0.04	2.04
Risophora minorinta	9.94	0.18	0.03	0.22	2.50	0.38	1.20	0.22	1.37	0.01	1.38

[a] Analyst: I. M. Rozanova

Biological Factors in Soil Formation

In the tropics the effect of biological factors on soil formation is characterized by a maximum intensity and continuity of action in both the annual and the secular development cycles. This is due to climatic peculiarities and the exceptional diversity and activity of flora and fauna which control the transformation of the abiotic environment. In addition to the cycle of materials in the plant-soil system and the action of the decomposition products of organic substances on the soil surface, an accumulation of the latter takes place by means of a complex interaction of plant and animal organisms with the atmosphere at different levels above the soil surface and without direct participation of the soil. We have in mind epiphytic growths that create unique aerial soil formations in which a considerable quantity of organic and ash material accumulates to enrich the soil. Table 1 gives analysis data for ash content of two species of epiphytes and "baskets" of dead organic matter formed by them on trees. Ca, Al, and K accumulate in largest quantities in such baskets, and SiO_2 accumulates in the rhizoids of orchids. All materials are characterized by a high nitrogen content.

The accumulation by such means of organic and ash materials may be illustrated by the following approximate calculations: the weight of "baskets" in an air-dry state is appr. 3–5 kg, and the number of "baskets" per hectare varies from 300 to 600–700. It follows that their contribution to soil enrichment is considerable. It should be remembered that the epiphytes' ash requirements are met by accumulation from the air or by animal participation.

The accumulation of ash and nitrogen contents varies in the leaves and needles of the tropical woody species and reaches considerable proportions (Table 2). Their composition differs little from the leaves and needles of the oak, pine, and other species which grow in the forest- and forest-steppe zones of the USSR, but several species are characterized by their great absorption of inorganic substances, primarily SiO_2, SO_3, K_2O, and

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khuan, Pzhan Chzhun-min, Chzhao Chi-go, Gun Tszy-tun, Chzhou Go-chu, Vay Chi-fen', and others. Analytical soil analyses were done in the forest-soil laboratories of the Forestry Institute, Academy of Science, USSR, and in the chemical-soil laboratories of the Soil Institute of the Academy of Science, China Peoples Republic.

MgO. Attention is called to the considerable variations in individual ash contents as well as the small consumption of them by pines and Casuarinae. The ash content of pine needles varies considerably, not only in relation to the composition of parent materials, but to erosion. (On granites the soil is severely eroded.) It is significant that the tree species of the tropics accumulate very little SiO_2 in their leaves, whereas herbaceous vegetation contains a large amount of SiO_2 and very little CaO, MgO, and Al_2O_3.

All these peculiarities of the ash composition of the deciduous parts of tree species effect the accumulation of ash elements in the soil. As far as the accumulation of ash elements is concerned, the tree species of the tropics are not inferior to our own. If we consider the fact that the percentage of such elements as Ca, Mg, Si, and P in tropical soils is extremely low, the importance of the selective absorption of these by forest vegetation becomes even more significant.

The behavior of organic matter on the soil surface under various plant formations in the tropics is just beginning to be studied. Its conversion into humus and the composition of the latter have been the least investigated and are not used as indices in establishing differences in the genetic properties of soils in spite of the fact that organic substances which accumulate on the soil surface under various formations of tropical vegetation not only determine the humus content, but its composition as well. (See Table 3.)

Without going into a detailed analysis, let us note the definite relation of the C_{humic}/C_{fulvic} ratio, not only in soils from vegetation which create large formations: forest, savanna, and mangrove, but in soils of obvious change of composition within these formations. Especially indicative are the differences between the broad leaf evergreen- and the deciduous, as well as the pine forests. The soils under savanna vegetation are heterogenous as far as organic content is concerned. Outstanding among them because of greater acidity are the soils under the meadow-savanna tall grass vegetation.

Soils of the mangrove forests with diurnal below- and above-water dynamic systems are characterized by dense humus accumulations. The composition of the humus is different than that in soils under other formations.

Such are several facts showing that biological

TABLE 3

Group content of organic matter in tropical soils under various plant formations[a]

Profile No.	Soil and location	Plant formations	Total C, %	C in compounds in % of total C converted to 100						C humic acid/C Fulvic acid
				Waxes-resins	Extracted with decalcification	Humic acid (Cr)	Fulvic acid (Cf)	Soluble in 0.1 N H_2SO_4	Non-hydrolysed residue	
24	Zheltozem, Yunnan	Primeval moist tropical evergreen forest	1.97	2.0	2.0	24.9	28.4	5.1	37.6	0.87
30	Reddish colored, savanna-forest	Same, but deciduous forest	2.54	5.1	2.0	24.8	16.5	2.8	48.8	1.50
13	Zheltozemic, peninsula Laichzhou	Secondary moist tropical forest	2.81	3.6	5.7	7.4	32.0	13.2	38.1	0.23
22	Krasnozem, Yunnan	Pine, secondary	4.56	4.2	2.4	9.2	19.5	3.7	61.0	0.47
11	Clay-bog, island of Hainan	Mangrove	6.73	8.2	4.2	22.4	22.0	1.6	41.6	1.02
21	Cinnamon-brown, savanna Yunnan	Savanna	1.49	4.0	3.0	31.0	16.8	8.1	37.0	1.84
26	Cinnamon-brown, krasnozemic, Yunnan	Secondary savanna	3.47	4.0	2.6	27.1	23.7	6.9	35.7	1.14
7	Meadow-savanna, island of Hainan	Secondary savanna	2.34	5.1	5.1	13.3	28.2	9.8	38.5	0.47

[a] Analysts: D. F. Sokolov, T. I. Yuneyeva and A. S. Dubkova

factors under tropical conditions, as well as elsewhere, can determine the direction of the soil formation process, and that among them vegetation is not a passive, but an active factor which stipulates the transformation of the physical-chemical properties both of the old weathered layers and the new weathering products of surface materials. Nevertheless, the manifold manifestation of the effects of vegetation formations and their transformation in soil formation and evolution remains outside the area of investigation of scientists because of the established concept that the weathering processes are more important than the others. Hence, they are accepted as basic.

Allitization of the Weathered Layer and Its Significance in Soil Formation. The soils of the tropical regions of China are formed both on old and new weathered layers of rock, all of which are allitized, despite depth or age. The degree of allitization, if judged according to total composition of the clay fraction, approaches <1 μ (Table 4).

In spite of substantial differences in the chemical composition of basalts, crystalline schists, and granites, practically equal amounts of Al_2O_3 are formed from them by weathering, and thus one stage of weathering with an accumulation of similar quantities of kaolinite is characterized. The differences in the contents of SiO_2, Fe_2O_3, and TiO_2 in the soils are caused not so much by the degree of rock weathering as by their composition. This is shown in the mineralogical composition of the clay minerals: according to thermal and x-ray analyses, kaolinite, alunite, allophane and goethite predominate in soils developed on basalts, and kaolinite, illite, goethite, quartz, muscovite, and allophane are present in soils on crystalline schists. Such differences in the composition of the clay minerals cannot be taken as a basis for dividing soils into groups; rather the various accumulations of ash and organic substances in the soil may be associated with them inasmuch as the exposed clay minerals do not have similar physico-chemical properties.

TABLE 4

Degree of allitization of clay fraction (<0.001 mm. in diameter) of soils developed on weathered materials of various rocks, % of clay fraction[a]

Rock and location	Depth, cm.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	$SiO_2:Al_2O_3$	$SiO_2:R_2O_3$	Particles < 0.001 mm. in diameter
On basalt, Shiwon, peninsula Laichzhou	0–5	28.53	34.10	15.62	1.62	1.41	1.13	67.0
	5–25	28.23	35.58	16.94	1.51	1.30	1.07	66.0
	25–55	28.88	36.06	20.74	1.95	1.36	1.05	77.0
	Below 55	29.39	35.48	18.72	1.53	1.40	1.07	—
On crystalline schist Tunfang, island of Hainan	0–15	39.93	31.08	12.29	0.11	2.18	1.78	18.4
	15–40	40.56	30.57	11.78	0.21	2.25	1.87	22.1
	40–60	40.75	30.92	12.44	0.07	2.24	1.83	24.9
	60–80	40.58	31.03	12.93	0.21	1.83	1.80	27.0
On granite Kwantung	0–20	37.38	36.34	11.28	1.44	1.75	1.47	18.9
	20–45	37.25	36.54	11.54	1.33	1.73	1.45	18.3
	45–100	36.47	36.32	10.95	0.98	1.71	1.46	34.0

[a] Analyst: Prof. Lee Chiang-Kwei.

If it is considered correct to pose the problem in this manner, a tropical soil profile should indicate the actual soil formation section with composition and properties which are dependent upon the interaction of biological and mineralogical factors as well as a section which is primarily the result of weathering processes. Such a division would, of course, be conditional, but might prove to be useful in the clarification of genetic soil properties. In the thick layers of old weathered red strata this may be detected by an analysis of the total composition (Table 5).

The soil in Profile 13 shows quite clearly a leaching of CaO, MgO, and SO_3 to a depth of 132-cm. and an accumulation of P_2O_5 and MnO in the upper 10 cm. layer with a decrease to the same depth. Redistribution of SiO_2 is observed in the upper 90 cm. layer, and of Al_2O_3 in the upper 2 m. section. Fe_2O_3 shows no variation throughout the entire 16 m. section.

In the soil of Profile 18 a pronounced break in the content and distribution of CaO, MgO, SiO_2, and P_2O_5 is observed at a depth of 170 cm., of Al_2O_3 at 3.5 m., and of Fe_2O_3 at 140 cm.

We are inclined to assume that the noted redistribution of oxides is caused by the new soil formation process that has been imposed on the old weathered layer. There is to be observed, moreover, a better defined biological accumulation of CaO, P_2O_5, and MnO in the soil of Profile 13 which is located under secondary moist-tropical forest, and leaching in the soil of Profile 18 where the forest vegetation has been destroyed.

The uniform distribution of iron according to profile is noteworthy not only in the soils examined but in all tropical soils, indicating its low mobility. Professor Li is of the opinion that iron in tropical soils performs the same function as calcium in chernozems. As analyses of investigated soils show, the protective function of iron

TABLE 5

Total chemical content of tropical soils on intensely red weathered material, % of absolutely dry soil[a]

Profile No.	Location and material	Depth, cm.	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	P_2O_5	MnO	CaO	MgO	SO_3	Particles <0.001 mm. in diameter
13	Peninsula of Laichzhou on weathered products of basalts and tuff-basalts	0–10	31.96	47.86	37.61	10.07	0.173	0.201	0.944	0.192	0.281	58.0
		30–40	32.91	47.81	37.73	9.92	0.161	0.197	0.671	0.278	0.428	61.6
		80–90	34.17	50.09	40.04	9.91	0.141	0.164	1.725	0.412	0.455	63.1
		118–132	32.78	53.33	41.62	11.56	0.141	0.179	2.256	0.545	0.461	53.5
		2 M	31.36	56.06	45.21	10.75	0.097	0.261	None	0.134	0.275	—
		4 “	32.00	55.58	43.83	11.65	0.092	0.124	0.058	0.179	0.233	69.4
		8 “	40.89	55.69	44.62	10.78	0.279	0.046	None	0.249	0.221	12.6
		14 “	37.55	54.61	42.25	12.13	0.222	0.321	0.119	0.358	0.154	6.09
		16 “	38.93	55.65	44.60	10.93	0.122	0.195	0.060	0.281	0.008	27.1
18	Kunmin Botanical station AN-KHR[b] on basalts	0–10	25.48	58.90	41.74	16.98	0.183	None	0.092	0.074	0.105	—
		25–35	29.81	57.74	35.67	18.96	0.107	0.013	0.123	0.103	0.112	—
		50–60	26.15	58.35	39.19	19.01	0.146	0.015	0.088	0.213	0.146	—
		130–140	30.41	58.90	38.78	20.01	0.105	Trace	0.148	0.184	0.300	—
		160–170	44.41	57.89	39.38	18.44	0.065	“	0.119	0.111	0.182	—
		3–3.5 M	28.12	58.21	39.25	18.78	0.179	“	0.222	0.051	0.188	—
		4.5–5.5 “	32.08	56.97	37.85	18.84	0.274	“	0.101	0.067	0.239	—
		12 “	34.84	54.46	35.86	18.35	0.252	“	0.115	0.082	0.219	—

[a] Analyst: V. S. Forova

[b] Academy of Science, China Peoples Republic

is shown by the fact that tropical soils as a rule are not podzolized.

Finally, the data of total analyses show very substantial differences in iron content (Tables 4 and 5), according to which soils may be divided into two groups: those with a higher iron content on basic rocks, and those with a lower content on acid rocks. The former are typically red in color (ferritic), the latter yellowish-red (allito-ferritic). We shall return to their genetic properties, but once more we emphasize the fact that neither allitic properties nor differences in composition of the clay minerals can be accepted as reliable indicators of type differences in tropical soils.

Several Peculiarities in Tropical Soil Formation. The natural development of the soil formation process under tropical conditions is determined primarily by forest vegetation. Under its basic types: evergreen moist-tropical-, dry deciduous-, coniferous-, and mangrove-forests, are formed the genetic soil groups with varying biological accumulations of ash and humus substances and their effect on the mineral fraction. Their evolution is brought about by the change of forest vegetation to grass-savanna, the result of cutting and burning the forests. It is possible that under certain circumstances the savanna vegetation may be primary and that the soils beneath it have an independent development not associated with forests. Thus among the savanna soils primary and secondary soils are distinguished in one or another stage of retention of the characteristics and properties of former forest stages of soil formation.

The evolution of forest soils in savannas can be detected only in areas which have not undergone intensive erosion after forest destruction. Erosion under tropical conditions is the most important factor in the destruction of soil and the renewal of soil formation. Its great progress complicates the isolation of basic soil groups as well as their state of evolution. This is especially true regarding the extent and area of the krasnozem soil formation, and the understanding of it is primarily based on color rather than on properties determined by the specific effect of vegetation. Very frequently soils eroded to a greater or lesser degree are related to this type, regardless of the previously developed type of soil formation, as are exposed red weathered layers. In their formation krasnozems are not associated with moist tropical forests; their development is related to dryer conditions. Iron present in them is not subject to hydration and is present in the form of free oxides or in combination with humates. The subgroup variation is determined by the action of deciduous and pine forests as well as the herbaceous vegetation converting to savanna.

The basic and most prevalent type of soil formation is the zheltozem which forms beneath the moist tropical evergreen forests (primary and secondary). Characteristic of this group is the great accumulation of mobile brown humic and fulvic acids reacting with the mineral fraction to cause hydration of the iron oxides and an increased content of the complex ferro-organic compounds, which result in no iron precipitation. This causes their predominantly yellow and yellow-orange color to the depth of the most intense percolation of water-soluble humus compounds. Below this they change to a red layer which represents either an ancient laterized weathered layer or a younger allitization.

The subgroup variation in zheltozems is caused by transformations in the composition of the moist tropical forests and the soil formation materials. Their development at different levels is also a factor in their composition and requires further study.

The zheltozem group of soil formation is most characteristic of the moist tropical conditions of China, and to us it appears to be original or primary, whereas the krasnozem group is secondary, or a derivative of zheltozem. Under certain conditions, e.g. under deciduous forest, it may be primary. In either case it is a transition or a connective of zheltozems with the savanna cinnamon-brown krasnozem group of soil formation. The latter group exhibits features of post-forest development. This is especially manifest in areas which have not been subject to erosion.

Laterite formations of iron found in secondary accumulations in the soil surface in the form of concretions and ferruginous layers, (as a result there occurs a loss of natural fertility), are not found in tropical China. One cause of this is the intensive erosion occurring with the beginning of soil utilization for agriculture when soils in the early stages of laterite formation are constantly subjected to erosion.

An unusual type of soil formation is developed in the fluctuating water conditions beneath mangrove forests where the daily ebb and flow of the sea water is of great importance, and as a result the water is both a direct and indirect factor in soil formation. By indirect is meant the consumption of mineral substances from the water by vegetation and their regression with the ebb tide. Under mangrove forests we therefore find an unusual cycle of substances including not only soi and vegetation, but sea water as well. In spite o flooding, there takes place an intensive humu formation under the mangrove forests with th participation of animal life which saturates th soil on a background of an intensive gleizatio and accumulations of mobile iron compounds.

A Brief Analysis of Basic Tropical Soil Groups The reviewed principles of development of th main tropical soil groups in association wit vegetative types and their transformations ar clearly expressed in the mineral and organi fractions of these soils.

Zheltozems under moist tropical forests are characterized (Table 6) by a clearly defined descending progression of the clay fraction which is evidently of kaolin composition, as analyses show an increase in content of total and mobile Al compounds (according to Sokolov). The redistribution of the total content of iron is considerably less and its mobile forms (Kirsanov) accumulate in the upper horizons. In a background of general impoverishment in soils of Ca and Mg, their secondary accumulation in the upper 10 cm. layer is evident and is indicated by an increase in total and exchangeable quantities of these elements and by a decrease in exchangeable hydrogen. The increase in the content of the latter with depth is evidence of a predominantly downward movement of the soil solutions. This is substantiated by a certain increase of SiO_2 in the upper 25 to 40 cm. layer and by the predominance of fulvic over humic acids, the marked increase in their content with depth, and the low ratio of humic to fulvic acids.

Despite the acid character of the soil, marked leaching is not accompanied by podzolization. Translocation of the clay fraction takes place without its decomposition as indicated by the analytical data (see Table 4, soil on basalt).

Variation in the composition of the mineral fraction of the soil is dependent upon the type of parent material, while variations in humus are dependent upon the character of the forests growing upon them. The latter also qualify the variations in the biological accumulations which impede development of the laterization process. This process is not evident even in the soils developed on materials weathered from basalts, which should be favorable for laterites.

In contrast to zheltozems, the krasnozems are

TABLE 6

Analytical data for zheltozems under moist-tropical evergreen forests[a]

Profile No.	Soil and location	Depth, cm.	Particles <0.001 mm. diameter	Humus, %	pH in water	Total content, % of absolutely dry soil basis					Exchangeable cations, mg/eq.			Sum of exchangeable cations, mg/eq.	Mobile		Organic group content, % of crarbon				C Humic acid/C Fulvic acid
						SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ca^{++}	Mg^{++}	H^+		Al^{+++}	Fe^{+++}	C Humic acid (Ch)	C Fulvic acid (Cf)	C hydrolysed in 0.5 *N* H_2SO_4	C Non-hydrolysed residue	
4	Zheltozem on reddish colored material from granite. Hainan island. Elevation 700 M.	2–8	24.5	3.62	5.43	66.52	16.29	2.09	0.71	0.15	3.39	3.39	0.50	7.28	0.20	14.92	13.2	31.1	8.9	38.4	0.42
		15–25	32.5	2.32	4.87	65.52	17.80	2.12	0.57	0.31	0.69	1.76	1.64	4.09	1.25	13.46	10.2	31.5	9.3	36.1	0.32
		45–55	39.0	1.98	4.88	58.65	22.46	2.84	0.86	0.54	0.70	1.82	2.24	4.76	2.95	6.47	8.4	32.6	10.9	34.9	0.26
		85–95	37.6	1.61	4.85	59.45	19.65	2.47	0.96	0.30	0.45	1.14	2.40	3.94	2.45	5.27	—	—	—	—	—
		130–140	30.0	—	4.79	61.09	24.44	1.75	1.27	0.37	0.45	1.14	2.20	3.79	2.13	4.38	—	—	—	—	—
24	Zheltozem on reddish colored material from sandstone. Yunnan. Elevation 870 M.	2–10	16.7	5.29	5.01	88.64	6.19	1.92	0.12	0.61	2.54	1.90	3.10	7.54	0.95	20.70	24.9	28.4	5.1	37.6	0.87
		15–25	15.0	1.61	4.84	88.09	6.24	2.02	0.12	0.64	0.40	0.80	2.70	3.90	1.92	39.60	28.5	22.7	7.1	32.1	1.26
		30–40	—	0.94	4.69	77.08	7.68	2.23	0.05	0.58	0.81	0.41	4.10	5.32	3.55	23.62	21.2	30.7	7.7	30.8	0.69
		45–55	27.2	0.79	4.55	81.01	10.83	3.44	0.03	0.48	0.41	0.41	4.20	5.02	4.07	15.54	—	—	—	—	—
		60–70	—	0.69	4.63	74.35	12.70	3.44	0.03	0.36	0.81	None	4.00	4.81	3.97	11.73	—	—	—	—	—
		80–90	30.0	0.50	4.48	78.79	12.44	3.84	0.03	0.32	0.41	0.20	4.21	4.82	4.13	7.66	—	—	—	—	—
		100–110	31.5	0.28	4.60	78.58	12.72	3.86	Trace	0.29	0.21	0.36	3.50	4.07	3.85	6.72	—	—	—	—	—

[a] Analysts: V. S. Forova, E. A. Kusmina, A. K. Aleshina, D. F. Sokolov and N. A. Vznuzdayev

distinguished by the obvious eluviation of the soil mass that is effected by soil formation. This is expressed in the pronounced downward movement of SiO_2, R_2O_3, CaO, and MgO (Profile 18, Table 5, and Profile 22, Table 7), accompanied by redistribution of clay fraction (Table 7), and the marked formation of illuvial horizons which are determined by the composition of the reactive humus materials.

In the soils under forests of *Pinus jnanensis* (Profile 22, Table 7), humic and fulvic acids are predominant and increase with depth. Under deciduous forests (Profile 30, Table 7) the humic acids prevail, but there is a sharp change in the ratio of humic to fulvic acids. With this difference in the composition of the humus materials certain features appear that are associated with the podzolization process. In the krasnozems under pine forests it is manifest in the increased content of SiO_2 at a depth of 4 to 12 cm. and in an impoverishment in Al_2O_3, Fe_2O_3, CaO, and MgO in the material lying immediately below the forest litter. This is especially effective on the composition of the exchangeable cations: under pine at a depth of 2 to 4 cm. where the biological accumulation of Ca and Mg is insignificant, hydrogen is predominant. Under oak forest there is a noticeable accumulation of Ca and especially Mg, and a decrease in H. Under deciduous forests a further increase in exchangeable Ca and Mg, and a decrease in H takes place. The quantity of mobile Al and Fe is significantly increased in comparison to the zheltozems, especially under oak forests. The increase in mobility of Al and Fe is dependent not only upon the forest vegetation, but also upon the composition of the parent material.

The krasnozem type of soil formation thus differs from that of the zheltozems in the greater mobility of the colloidal fraction and in the leaching process connected with the occurrence of the biological accumulations of savanna character. Only in soil groups under pine forests is the podzolization process established; consequently, its occurrence does not follow a zonal distribution. The following separation of krasnozems into subgroups has been arranged:

1. Podzolized krasnozems under pine forests, 2. Strongly leached red soils under oak forests, 3. Red soils with secondary saturation (savanna forest) under deciduous forest.

The cinnamon-brown krasnozem group (Table 8) is characterized by the occurrence of two opposing processes: leaching and accumulation (both biological and thermal). The leaching is expressed in the higher content of mobile Al with depth (Table 8), which is correlated with the quantity of fulvic acid. Thermal accumula-

TABLE 7

Analytical data for krasnozem soils under pine and broadleaf forests and for clay-bog soils under mangrove forests[a]

Profile No.	Soil and location	Depth, cm.	Humus, %	pH in water	Total content, %					Exchangeable cations, Mg/eq.			Sum of exchange able cations, Mg/eq.	Mobile		Organic group content of humus, % of carbon converted to 100				C Humic acid/C Fulvic acid	Particles, <0.001 mm. in diameter
					SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ca^{++}	Mg^{++}	H^+		Al^{+++}	Fe^{+++}	C Humic acid (Ch)	C Fulvic acid (Cf)	C Hydrolysed in 0.5 N H_2SO_4	C Nonhydrolysed residue		
22	Krasnozem on reddish colored material from schist under pine forest Yunnan	2–4	5.46	4.53	65.97	13.03	4.31	0.15	0.35	2.71	1.67	8.50	12.88	4.31	14.84	9.2	19.5	3.7	61.0	0.47	48.0
		4–12	2.69	4.79	67.51	15.92	5.06	0.15	0.47	1.03	0.20	3.54	4.77	4.54	13.03	12.0	21.9	3.3	53.5	0.55	60.1
		17–27	1.25	4.67	61.73	20.63	4.75	0.18	1.03	0.41	0.41	3.73	4.55	4.48	14.81	10.4	23.0	4.6	47.1	0.45	64.2
		40–50	0.96	4.60	—	—	—	—	—	0.41	0.10	4.00	4.51	4.77	8.30	—	—	—	—	—	71.5
25	Reddish colored soil on sandstones under oak forest Yunnan	3–9	2.65	5.32						1.41	5.80	None	7.21	0.28	105.20	—	—	—	—	—	
		10–15	1.10	4.91						0.41	1.22	3.80	5.43	2.72	119.00	—	—	—	—	—	
		20–30	0.68	4.95						0.40	1.02	4.30	5.72	4.62	68.90	—	—	—	—	—	
		42–52	0.22	4.88						Trace	1.00	2.02	3.02	2.24	15.84	—	—	—	—	—	
30	Reddish colored savanna-forest soil on sandstones under deciduous forest Yunnan	2–7	4.15	4.81						3.34	1.14	5.32	9.80	2.03	17.92	24.8	16.5	2.8	48.8	1.50	
		7–16	1.67	4.79						1.02	1.33	3.62	5.97	3.64	17.19	29.3	23.9	3.3	33.8	1.22	
		20–27	1.70	4.84						0.60	1.21	3.00	4.81	3.18	15.22	—	—	—	—	—	
		48–57	1.13	4.86						—	—	—	—	—	—	—	—	—	—	—	
11	Clay-bog soil under mangrove Hainan island	0–10	3.13	4.45						1.35	2.91	1.61	5.87	0.26	85.41	—	—	—	—	—	
		15–25	3.05	4.21						1.35	6.31	2.00	9.66	0.32	107.93	—	—	—	—	—	
		40–50	0.32	4.43						2.70	8.09	1.94	12.73	0.45	74.30	—	—	—	—	—	
10	Same Hainan island	0–15	5.39	5.72						5.74	13.54	5.60	24.88	3.25	252.40	22.4	22.0	1.6	41.6	1.0	16.90

[a] Analysts: V. S. Forova, A. K. Aleshina, E. A. Kuzmina, D. F. Sokolov

TABLE 8

Analytical data for cinnamon-brown krasnozemic soils under savanna vegetation[a]

Profile No.	Soil and location	Depth, cm.	Humus, %	pH in water	Exchangeable cations, Mg/eq.			Sum of exchangeable cations, Mg/eq.	Mobile		Organic group content of humus, % of carbon converted to 100 C				C Humic acid/C Fulvic acid	Particles <0.001 mm. in diameter
					Ca^{++}	Mg^{++}	H^+		Al^{+++}	Fe^{+++}	C Humus acid (Ch)	C Fulvic acid (Cf)	C Hydrolysed in 0.5N H_2SO_4	C Nonhydrolysed residue		
21	Cinnamon-brown savanna primary Yunnan	0–10	2.61	5.89	4.87	3.25	None	8.12	0.07	5.53	31.0	16.8	8.1	37.0	1.84	21.4
		20–30	1.05	5.43	3.04	0.41	“	3.45	0.09	6.77	28.0	14.0	8.0	36.0	2.00	27.7
		40–50	0.38	4.91	5.07	Trace	“	5.07	1.75	10.04	20.0	24.0	4.0	36.0	0.84	30.8
		70–80	0.20	4.70	1.42	0.20	2.07	3.69	2.36	9.45	—	—	—	—	—	33.4
26	Cinnamon-brown krasnozemic, forest Yunnan	0–4	5.55	5.02	2.72	1.44	4.43	8.14	1.67	15.46	27.1	23.7	6.9	35.7	1.14	28.4
		5–13	5.14	4.81	0.83	2.70	8.32	11.85	2.69	9.28	25.1	24.2	7.1	37.1	1.04	33.5
		15–25	3.13	4.79	0.61	0.40	4.25	5.26	2.75	12.58	26.2	23.3	7.9	34.2	1.13	39.4
		30–40	1.27	4.81	0.40	0.20	2.40	3.00	5.34	8.30	18.3	29.0	9.7	34.4	0.63	—
		50–55	0.47	4.72	0.20	0.20	2.00	2.40	2.34	6.50	—	—	—	—	—	42.4
		70–80	0.39	4.77	Trace	Trace	1.23	1.23	2.19	5.88	—	—	—	—	—	—
5	Meadow-savanna dark Hainan island	0–10	5.06	4.95	0.90	3.38	4.00	8.28	1.36	17.58	20.1	21.4	2.0	49.6	0.85	18.9
		12–22	3.02	4.81	1.02	0.33	4.00	5.35	2.28	15.62	20.6	20.6	3.2	45.3	1.00	23.7
		30–40	2.34	4.81	0.45	1.35	3.00	4.80	2.34	16.32	—	—	—	—	—	26.1
		50–60	1.50	4.96	0.68	2.03	2.00	4.71	2.00	7.86	—	—	—	—	—	38.3
		75–85	1.44	5.08	1.02	1.00	2.00	4.02	1.82	6.40	—	—	—	—	—	37.5

[a] Analysts: V. S. Forova, E. A. Kuzmina, A. K. Aleshina, N. A. Vznuzdayev, D. F. Sokolov

tion is indicated by the upward movement of mobile iron into the surface horizons. Biological accumulation definitely occurs in the increase of exchangeable Ca and Mg in the humus horizon.

In contrast to the previous groups, in the composition of the humus material humic acids are predominant and there is an increase in hydrolyzed compounds. For these soils the ratio of humic acids to fulvic acids fluctuates characteristically from 1 to 2 comparable to our gray and dark gray forest-steppe soils. Removal of the clay fractions is clearly traceable to an appreciable depth but there are no accompanying features showing the prevalence of podzolization. Beside this, in the secondary (post forest) savanna soils an increase in the content of exchangeable H is noted, especially in the humus horizons which we are inclined to believe is due to a greater inflow of water and insufficient saturation (profiles 26 and 5).

In the primary savanna soils (Profile 21) exchaneable H is found only in the lower horizons as a result of the leaching of the acid products of the soil formation in which saturation with Ca is predominant.

The following subgroups are distinguished among these soil groups:

1. Cinnamon-brown krasnozem, 2. Dark krasnozem (meadow krasnozem) 3. Cinnamon-brown savanna.

The first two subgroups are formed under secondary, post forest, savanna vegetation. For these soils residual non-saturation is characteristic and is due to their being evolved from zheltozems under conditions of varying moisture. Cinnamon-brown savanna soils, belonging to the third subgroup, are characteristic of primary and secondary savanna where their occurrence is due to the much longer influence of the latter than the first two subgroups.

Mangrove soils (Table 7, Profiles 10 and 11) are related to the unique, clay-bog group formation. They differ from others in the increased content of humus and in that they have equal quantities of humic and fulvic acids. Characteristic features of their chemical composition are the predominance of exchangeable Mg and an unusually high content of mobile iron with insignificant quantities of mobile Al. Notwithstanding the alkaline character of sea waters, these soils have an acid reaction. Their distinguishing features are due to the qualities of the flood waters. The soil from Profile 10 had developed in a zone that is for the most part covered with sea water, while the soil from Profile 11 developed in a zone of supplementary flooding with mixed river and sea waters. The former is more saturated with Mg and contains more mobile iron.

Examination of the several tropical soil groups and a study of their genesis allow us to conclude that in spite of the special features of weathering and the formation of peculiar red zones of weathering, soil formation on these is to a large extent dependent upon the composition of the vegetation, whether forest or savanna formations, and within each upon types and the changes brought about by the cutting and burning of forests.

One of the major factors determining evolution of soils is the composition of the organic matter and the character of the interaction of its decomposition products with the mineral fraction of the soil. These are instrumental in the differentiation of soils into group and subgroups. Such an approach to the study of tropical soils has made it possible to reveal with greater depth and objectivity the nature and fundamental principles of the development and evolution of soils.

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EFFECT OF WATER RESERVOIRS ON SOILS

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THE construction of large water reservoirs causes substantial changes in the natural conditions of adjacent regions. Water reservoirs also influence the underground water régime and the process of soil formation.

A number of studies have been made of natural conditions in areas where hydroelectric stations are to be built. These investigations also give a prognosis of the changes to be brought about by the construction of water reservoirs. A very thorough study on this subject was made by the Volga-Kama expedition organized by the V. V. Dokuchayev Soil Institute, Acad. Sci., USSR. Results are given in resumé form in the article by Rohde (4). However, changes in soil cover found in areas adjoining existing water reservoirs have been insufficiently studied.

The present article investigates the effect of water reservoirs of forest strips on ground waters and soils. The study was made by members of an expedition organized by the department of physics and soil melioration of Moscow University.[1]

The work was done during the summer of 1957, at the sites of Rybinsky, Ivan'kovsky and Istrinsky reservoirs. Profiles were cut perpendicular to the banks of the reservoirs. Altogether, six profiles were marked off at Rybinsky reservoir, four at Ivan'kovsky, and six at Istrinsky. These profiles were located in areas where flooding was severe. In selecting locations, we aimed to include as fully as possible the diverse natural environments of the reservoir areas investigated. On the profile site, the location was leveled, soil samples were taken, and observations were made on soil moisture and certain physical and moisture properties including ground-water level.

Effect of Reservoirs on Ground-water Regime

Observations on the behavior of ground-water were carried on mostly in the Darwin Reservation, at the Rybinsky water reservoir. The data used were obtained from profile "Borok" and profiles No. 1 and 2, laid out by the Forestry Project expedition in 1955. All the profiles were located on sod-podzolic soils close to the buildings of the reservation. Comparisons were made with data obtained from all the other profiles. The locations of holes made for profile "Borok" are shown in Table 1. Results are given in Figure 1.

The effect of this reservoir on the action of ground waters is noticeable in hole No. 80 which is closest to the shore. In this hole, the curve for ground-water level runs almost parallel to the curve for reservoir water level; it repeats its fluctuations. There is a maximum springtime level for hole Nos. 81–83, farther away from the reservoir. This level is reached sooner here than in the reservoir. This fact proves that the first maximum is associated with the spring rains. It is probable that the rise in water level of the reservoir also has some effect produced by pressure upon the underground water and by obstructing drainage.

From early May on, a drop in the level of underground water is observed in hole Nos. 81–83. There are temporary rises within this general drop (June 10th, July 1st, July 10th). These summer rises are more significant in test holes made far from the banks of the reservoir than in those close by. The cause for the rise in ground-water level is precipitation rather than fluctuations in the level of reservoir water. The water reservoir has a direct influence on the surrounding soil for a short distance only; this is also borne out by the fact that the ground-water table generally tends toward the water table of the reservoir. When the water level is high in test holes No. 80 and 81, the level of ground-waters corresponds to about the same marking or it is even lower than the level of the reservoir. Direct filtration of water into the banks can occur only at certain times. The filtration ceases near hole No. 81, 300 m. from the bank. The higher water table of the more distant drillings generally corresponds to the higher reservoir level; however, the two levels are not always the same.

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[1] The work was shared by scientific collaborator V. N. Kozlovskaya, laboratory aides L. V. Yakovleva and I. A. Mitrokhina, and by practice students of Moscow University. The author of the present article was head of the expedition. Prof. N. A. Kachinsky was scientific director. Additional materials used were a report by G. V. Dobrovol'sky, scientific assistant with the soil science department of Moscow University on soil studies at the Kalinin collective farm, Zavidovsky district, Kalinin region; and materials from the Darwin Reservation.

The balance of ground waters was calculated for No. 81. This hole is located in a depression beyond an elevation in the channel. The method of calculation is given by Lebedev (2). Calculated results are shown in Table 2.

An inflow of ground waters into the area of hole No. 81 was recorded throughout the entire observation period. A more detailed analysis of the water balance is not given here for lack of space; but a comparison of it with ground-water table gradients taken by periods indicates that this inflow comes mostly from higher sphagnum bogs. Besides, during the months of June to September when the reservoir water level is high, there is additional seepage from the reservoir. More water is added to the gound seepage in spring and fall from infiltrating rains. In summer, evaporation of ground-water is higher than the stored inflow.

TABLE 1

Location of holes at the "Borok" profile

Hole number	80	81	82	83
Distance from the bank, meters	57	296	455	594

An examination of the profile's soil showed that the elevation near the channel contains sod-podzolic soils with no traces of gley. Farther away, the basic soils are slightly sod-podzolic, slightly gleyed. There are water-logged depressions with humic-gley soils at a distance of 300 to 400 m. from the bank in the hole No. 81 area. Still farther, the gleying increases assuming the appearance of sphagnum bogs.

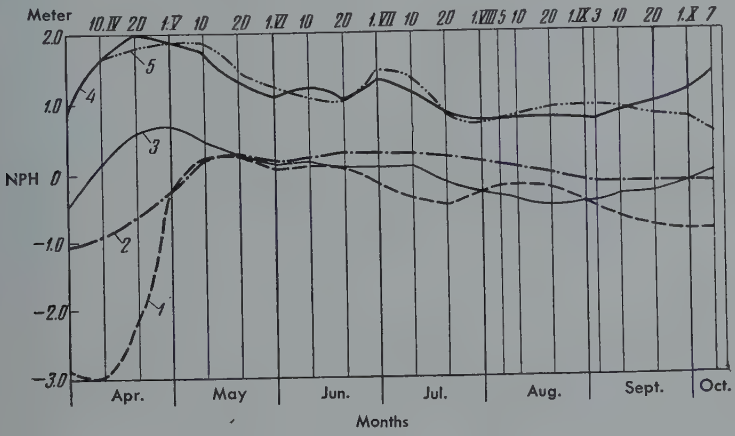

FIG. 1.—Profile *Borok*. Recordings for water levels in reservoir and underground waters in relation to normal pressure horizon (NPH), for 1957. 1—Reservoir; 2—hole No. 80; 3—hole No. 81; 4—hole No. 82; 5—hole No. 83.

TABLE 2

Ground water balance given in millimeters, for hole No. 81, 1957, Profile "Borok"

Period	Position of water in reservoir	Accumulation		Loss		Balance
		Inflow	Infiltration	Outflow	Evaporation	
Apr. 1st–Apr. 15th	Low	10.95	73.05	—	—	+84.0
Apr. 15th–May 1st	Increase	10.95	15.00	—	—	+25.95
May 1st–June 1	High	13.64	—	—	74.09	−60.45
June 1st–July 1	Beginning of drop	28.80	—	—	25.80	+3.0
July 1st–Aug. 5	Drop and rise at end of period	50.40	—	—	99.36	−48.96
Aug. 5–Sept. 3	Drop	32.19	—	—	43.21	−11.02
Sept. 3–Oct. 7	Drop	37.74	15.98	—	—	+53.72

TABLE 3

Location of test holes in profile No. 1

Hole No.	Distance from shore, m.	Remarks
17	143	Depression beyond the terrace
18	164	Gentle slope
19	231	“ “
20	298	Depression before the sphagnum swamps

TABLE 4

Inflow and outflow of ground water in profile No. 1

Hole No.	Predominance of inflow over outflow (+) or outflow over inflow (−) given in mm., during period from June 11 to Dec. 25, 1957	Remarks
17	+246.56	Movement of ground water from water shed to reservoir, i.e., from test hole No. 20 to No. 17.
18	−17.81	
19	−87.55	
20	+2342.0	

TABLE 5

Amount of rise in ground water table compared with NPH in profile No. 2

Hole No.	Distance from shore, mm.	Nov. 15, 1955	Nov. 1, 1957	Remarks
14	1148	+2.43	+2.83	Sphagnum bog
13	381	+1.29	+1.56	“ “
12	93	−0.23	+0.60	Ditchbank elevation
Water level of reservoirs	0	−2.34	+0.09	—

Another profile where observations were recorded is also located near the buildings of the reservation in a similar environment. The location of test holes is given in Table 3.

The amount of inflow and outflow of ground waters computed on their balance is given in Table 4.

This profile shows no infiltration of water from the reservoir into the banks. The delay in drainage is apparent here: in hole No. 20, at the mark +1.83 from the normal pressure horizon of the reservoir (NPH)[2], the inflow is noticeably greater than the outflow. Similar pressure from underground drainage was found in hole No. 17 which like No. 20, is located in a depression.

In all the profiles examined, the general movement of ground waters is directed toward the reservoir; only in a few cases at certain times does the underground stream flow from the reservoir out from the shore. This movement gradually ceases at a rather short distance (about 200 to 300 m.). But in general, a high ground-water table even in profiles of far-removed areas corresponds to a high water level in the reservoir, and vice versa. For example, our observations for profile No. 2 gave the following results: Table 5 shows a higher ground-water level in relation to NPH (normal pressure horizon) with either a low level of water in the reservoir (November 15, 1955), or with a high level (November 1, 1957).

The relation between reservoir and underground waters can be explained by pressure and a delay in underground and surface drainage. When the level of water in the reservoir is high the underground water table rises. This indirect effect of the reservoir extends over a rather long distance—up to one kilometer, as shown in the foregoing example.

The foregoing observations indicate that water seepage from a reservoir takes place when its water level is high. The seepage then extends over a distance of 300 to 400 m. During the rest of the time, drainage toward the reservoir is less than the inflow from the watershed, and the rise in the stored underground waters is brought about by the force of underground flow. There is no significant moisture accumulation noted under conditions prevalent in the Darwin reservation because the underground waters are lost through evaporation. This is facilitated by the coarse texture of the soils. Soils along the depressions become water-logged, while in elevated areas they are gleyed in the deeper horizons. This is the zone under direct influence of the reservoir. Farther along, its influence is indirect, and here too, a relation exists between the reservoir and the underground water, but only as a general underground flow and surface runoff.

Effect of Reservoir on Soils

The higher soil moisture content resulting from infiltrating waters and the pressure of underground and surface flow alters the process of soil formation and the type of soil cover in areas influenced by reservoirs.

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[2] NPH stands for normal pressure horizon of a reservoir.

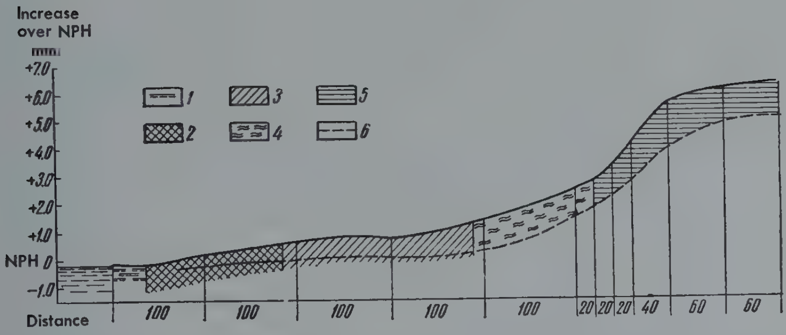

FIG. 2.—Soil profile. Budenny collective farm, Fofanovo village, Kalinin district. 1—Surface water; 2—peaty-gley and peaty-podzolic gley soil; 3—sod-meadow soil developed on sod-podzolic soil; 4—sod, strongly-podzolic, medium-gleyed soil; 5—sod, strongly-podzolic soil; 6—ground water table.

High moisture produces water-logged soils. Lower moisture produces a change in zonal soil formation into meadows. The characteristics of meadow formation are: meadow vegetation, formation of a sod horizon with a granular structure, and increased mobility of dark-colored humus substances which impart a deeper hue to the soil profile. Gleying of the lower soil horizons increases. The least perceptible effect of the presence of a reservoir is the gleying of the deeper horizons with no radical change in the general process of soil formation.

These more or less pronounced changes are observed in areas that adjoin reservoirs. As an example, we shall give a profile examined on the bank of Ivan'kovsky reservoir (Fig. 2). Several zones of reservoir influence were separated in the profile. These zones differed in kind of water supply and soil cover. Fifty meters away from the water edge, the water seeped up to the surface at the time observations were recorded. This zone is under water when the reservoir level is high, it dries out when the level is low. It is designated as a periodic flood area. Higher up is a strip of peaty-gley and peaty-podzolic-gley soils which we have termed the bog zone. Beyond it are the sod-meadow soils that had developed on sod-podzolic soils. This process is characteristic of the meadow-like formation zone. Finally, still higher, is the zone of soils turning to gley in the deep horizons. This terminates the extent of influence of a reservoir on soil in the territory surrounding it.

Because of the type of relief, all the zones in this profile are quite distinct over a rather short distance. Their extent and distinctness may vary under other conditions, so that some zones disappear.

Before turning to analysis of factual material, it is well to give a few definitions of terms. The term "waterlogging" (1) is used in literature on melioration and hydraulic engineering. This term signifies a negative action of the reservoir, producing a high moisture content and a swamp condition in the soil. Waterlogged soils become unsuitable for agricultural use. The cause of waterlogging is water seepage from the reservoir into its banks.

The present article analyzes the influence of a reservoir. By "influence" we mean both its negative and its positive action. Influence of a reservoir is a broader conception than "waterlogging" which implies a negative action. By comparing material from our study of profiles, we can give a more detailed description of the zones influenced by reservoirs. Some data that characterize the zones of influence and the extent of it are given in Table 6.

The effect of a reservoir is pronounced when the banks are shallow, with a slope less than 0.01 degree. If the slopes are over 0.01 degree, the presence of a reservoir has practically no effect on the soils. If the slopes are about 0.01 degree, the influence of a reservoir may be greater or less, depending on environmental conditions, especially the parent materials. On coarse sandy soils (as for example in the Darwin reservation), the influence of a reservoir is less pronounced than in finer-textured parent material (as at Istrinsky reservoir).

Usually, the water-logged zone does not form an uninterrupted belt of bogs and bog-like soils.

TABLE 6

Basic figures for zones influenced by reservoirs

Name of profile	Average slope	Water-logged zone		Meadow-like zone		Zones in the process of gley formation in deep horizons		Depth of ground-waters from surface, given in m. for zones:			Remarks
		Distance from shore	Increase over mark for uppermost zone limit above NPH[a]	Distance from shore	Increase over mark for uppermost zone limit above NPH	Distance from shore	Increase over the mark for upper limit beyond the NPH	Water-logged	Meadow-like	Gley in deep strata	
Rybinsky reservoir											
Veretye	0.069	none	—	none	—	250	+3.05	—	—	1.2–2.0	
Zakharyino	0.005	50	0.0	"	—	350	+1.18	0.6	—	1.3–2.0	
Ossinovik	0.008	none	—	"	—	200	+1.3	—	—	1.0–2.0	
Mishichino	—	365	+1.2	"	—	Gleyed soils merging with water-logged zone		0.3–0.4	—	1.0	Spotty water-logge along depressions marked to NPH+ 0.3. Gleyed soils above. Distinctly gleyed zone absent
Vauch	0.010	none	—	"	—	100	+1.4	—	—	0.5–1.0	
Borok	0.004	400	+1.0	"	—	400–600	+2.0	—	—	—	Gleyed soils also occur in water-logged zone
Ivan'kovsky reservoir											
Novinki	—	—	+0.41	—	+1.1–+1.5	—	+0.7–+2.9	—	1.7	1.0–2.5	Territory is separated by a ditchbank from the reservoir, so that soils of varying moisture are arranged not in zones but in spots
Fofanovo	0.005	200	+0.64	200–400	+1.44	400–500	+2.70	0.40	0.70	≈1.0	
Vlassovo-Mutnia	—	—	+0.48–+1.0	—	+0.6–+1.3	—	+1.13–+2.57	<1.00	1.00	≈1.00	Distinct zones absent. Soils of varying moisture arranged in spots, depending on microrelief
Bortsino	0.003	627.3	+1.82	Meadow-like and water-logged soils, in adjacent location		—	+2.0	0.8	1.07–0.63	1.35	Gleyed zone slightly defined
Istrinsky reservoir											
Frunzes	0.018	130.5	+2.38	—	—	—	—	—	—	—	Meadow-like and gley zones slightly defined.
Sinevo	0.010	>89.0	+0.87	—	—	—	—	0.0–1.7	—	—	Water-logged zones in depressions alternate with gleyed zones on elevations
Yakunino	0.010	108.5	+0.66	Meadow-like soils merging with water-logged zone		—	—	0.0–1.0	—	—	
Timofeyevo	0.002	432	+1.01	none	—	none	—	0.0–2.0	—	—	Gley zones occur in spots on water-logged zone
Lopotovo, profile No. 7	0.020	—	—	—	—	165	+3.41	—	—	0.5–2.9	Water-logged and meadow-like zone absent
Lopotovo, profile No. 6	0.100	—	—	—	—	—	—	—	—	—	No effect from reservoir

[a] Normal pressure horizon.

The water-logged depressions in this zone alterate with the less moist elevations where sod-meadow soils predominate. Meadow soils are bsent wherever the effect of the reservoir is less ronounced, in the water-logged zone; bog soils ccur in spots among podzolic, more or less gleyed oils. The water-logged depressions are covered with lowland-type bog vegetation.

We observed changes that took place in soils ver a period of 10 to 15 years. The formation f banks and the development of plant cover are ot yet completed. There is therefore reason to elieve that water-logged formation has also not eached its final phase, but will continue.

The water-logged zone extends over 600 m.; its upper limits vary between NPH (normal pressure horizon) and NPH + 2.8 m. Usually it exceeds the NPH by about 1 meter. The ground waters are less than 1 meter below the surface. The water-logged zone shows the negative effect of the reservoir. This zone should not be used for agricultural purposes or, if it has to be used, special meliorative measures should be taken.

The meadow-like zone is not always clearly delineated. It is often associated with the water-logged zone, the meadow-like soils occupying the elevations marked higher than 1.0 m. above NPH. In many instances it would be difficult to separate these zones.

There are two cases that should be differentiated in a spotty, mosaic-like complex of water-logged and meadow soils. The first is when bogs constitute the basic soils while the meadow soils are in the process of becoming bog-like; then both the bog and the meadow soils are parts of the zone of water-logged formation. In the second case, the basic soils are meadows; the process here is toward drying of bog soils. Both soil groups may be considered as belonging to the zone of meadow-like formation.

Examples of such a combination of meadow and water-logged soils are the profiles "Novinki" and "Vlassovo-Mutnia" at Ivan'kovsky reservoir. In the Novinki profile, the dominant process is meadow formation; here the meadow soils represent an independent zone, with spotty inclusions of water-log zone. In the second case, the bog-like process prevails and the meadow soils that occur among bog-like soils are evolving toward bog. The ground-waters under meadow soils are, as a rule, at a depth of 1.0 to 2.0 m.; the soil profile is being constantly wetted by capillary rise of the ground-waters. The upper limit for this zone is NPH + 2.0 m.

The zone of meadow-like formation should remain in agricultural use. Better conditions for cultivation of crops may exist in this zone than conditions that prevailed before the reservoir was constructed. In any case, the zone of meadow-like formation can be used for intensive cultivation with the use of suitable crops. Matveyeva (3) points out that there was an improvement in plant cover after the construction of a reservoir in the middle levels of the Volkhov River valley. This zone probably corresponds to our zone of meadow-like formation.

The least pronounced effect of a water reservoir on soils is the gleying of deep horizons. The formation of gley in the soil profile is very flexible: In years when the water tables of reservoir and underground water are high, gley formation increases while when the ground-water level drops and aeration improves, the symptoms of gleying decrease or even disappear altogether. Accelerated gley formation in deep horizons may be observed in coastlines with either shallow or steep slopes. The gleying is naturally less pronounced in the latter case and its symptoms are noticeable at a greater depth (in horizon C, in the lower part of horizon B).

Gley formation extends far from the banks in the entire zone indirectly influenced by the reservoir wherever surface and ground drainage are obstructed. Gleying may appear in spots along depressions where there is a localized accumulation of seepage. It is difficult to give the limits of this zone: it depends on local geomorphology, on lithology of the ground, on relief and the depth of water barrier. In our observations, the zone of gley formation varied in length from several hundred meters to one kilometer, and terminated at 1.5 to 3.0 m. marks above NPH.

Gley formation in the deeper horizons is a negative phenomenon; but it does not prevent the use of a territory for agricultural purposes. It is possible to produce good yields in such a zone with proper agricultural practices.

A number of measures should be considered in planning and exploiting water reservoirs. These would help use adjacent territories to better advantage and prevent certain undesirable effects. Whenever possible, the reservoir should be surrounded by high banks with a slope of over 0.01, built of coarse-textured soils. If local conditions are such that the area affected by reservoirs is large, the zone of periodic flooding should be reduced to a minimum by proper control of the reservoir, and the water-logged zone not used for agriculture. It may be utilized after constructing canals and drains to catch the water filtering from the reservoir and to channel it away from the area. It is advisable to use the water-logged zone for moisture-loving crops (such as perennial rice, willow). The problem of selecting suitable crops has not been sufficiently worked out at present.

A special plan of crop rotation should be devised for the meadow-like zone. It should include a high percent of forage crops, sown grasses, and late vegetables. The creation of artificial meadows is a possibility.

Conclusions

1. Water reservoirs have various effects on the surrounding territory, its ground-water and soils.

2. Ground waters are directly and indirectly influenced by reservoirs, as follows:

a) The direct effect of a reservoir on ground-water is felt over a short distance from the banks (about 300 m.). Water infiltrates the banks at this distance when the reservoir level is high.

b) The indirect effect consists of pressure exerted by the reservoir on underground and surface drainwaters and the resulting rise in the ground-water table. There may be seasonal fluctuations in water level associated with precipitation, aside from the general rise. The indirect influence of a reservoir may extend quite far, perhaps as far as the water divide.

3. Four soil zones, variously affected by the action of reservoirs, can be separated: a) zone of periodic floods, b) water-logged zone, c) meadow-like formation zone, and d) zone of gley formation in the deeper strata. These zones are more or less clearly delimited, depending on local conditions. Sometimes the zones are combined or absent.

4. The zone of periodic floods should be reduced to a minimum by an effective program of a reservoir's functioning.

5. The formation of a water-logged zone is mostly due to the direct effect of a reservoir on underground waters. The water-logged zone is delimited by elevation marks exceeding the normal pressure horizon by one meter. It is usable following proper melioration measures and selection of suitable crops.

6. The meadow-like formation zone requires a program of special crop rotation, the list of crops consisting of water-loving plants. The zone can be used more intensively than before the construction of the reservoir. Both the meadow-like zone and the gley formation zone are formed by indirect action of a reservoir on ground-waters.

7. The zone of gley formation in the deep horizons does not require any special treatment. The regular agronomic practices will assure good yields from soils of this group.

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HE ROLE OF GRASS VEGETATION IN SOIL FORMATION N THE MOSCOW RIVER FLOOD PLAIN

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THE long-range development and promotion of agriculture, one of the State's important goals, volves efforts to increase the fertility of culti- ated lands as well as to develop large virgin and bandoned areas. In the non-chernozem zones, ood plains and land covered by forest and rubs have been included in the group of aban- oned areas. However, at the present time, flood lains are intensively developed because they are aturally very fertile and because their soils are xcellent for growing forage crops and vegetables. he development and cultivation of flood plain ils considerably limit the natural processes of il formation, since man exerts greater influence this process.

This report attempts to elaborate on the extent which the character and rate of the biological ycle nutrients is changed when natural meadow egetation is replaced by cultivated crops.

Our investigations were conducted at the talin collective farm in the Vinogradov region f Moscow Oblast'. This farm is located on the wer course of the Moscow River where the -called "Faust" flats are located. The area is nown as one of the better developed river plain reas for vegetable growing. Our experimental lots were scattered over the well-developed cen- ral flood plain on the left bank of the Moscow iver, in deep sod-meadow soils. Structurally, hese soils are distinguished by a deep, uni- rmly-colored humus, the content of which is as igh as 6% in the upper horizons, gradually de- reasing until at a depth of one meter, it is often .0 to 1.5%. Total nitrogen content is quite high, .25 to 0.35%. Soil reaction is neutral, the pH t times fluctuating between 6.8 and 7.2. The il textures are fine silty, clay loams (4). Blocky- ranular structure is conspicuous in upper hori- ons, but becomes less evident at depths below 0 to 70 cm. because of greater water saturation. n the course of drying, a light-greyish powder ppears at times along structural contacts. ccumulations of small areas of greatly softened, anganese-ferrous concretions are observed hroughout the profile of sod-meadow soils. Pockets of light gleying are found at depths of one meter and below.

According to the literature (4, 6) and our own data, flood plain soils are poor in potassium available to plants although their total potassium content is fairly high, 3.11%.

In order to study the biological cycle of inorganic nutrients and nitrogen, tests were conducted on three different plots. The first plot contained the tall-grasses of the timothy-fescue meadow types, the meadow fescue and meadow timothy predominating. White spear grass was less abundant, while meadow foxtail and Kentucky bluegrass were widely scattered throughout. Caraway geranium, horse sorrel, and various other grasses were also found in the meadow. Detailed determination of the plant composition of the meadow and crops revealed that "mixed grasses" totalled only one-fifteenth of the total herbaceous vegetation.

For sampling purposes, the vegetation at various spots of the meadow were blocked out in five one-meter areas from which all vegetation was clipped off close to the ground. Plants were assorted according to species, dried and weighed. From the same areas, soil samples were taken (in sets of three) to determine the volume of the root systems. Samples were taken from a 25 × 25 cm. area, to a depth of 50 cm., by taking the first from the surface down to 25 cm. and the second from a 25 to 50 cm. depth. Unfortunately, separation of roots according to individual species of plants was impossible because they were too entangled, and all measurements were made on the basis of overall root mass. Soil particles adhering to the fresh roots were washed away very carefully in river water. After drying, the larger roots were cleaned by brushing. Experience shows that living roots are best freed of adhering soil particles in a strong current of clean, running water.

The second plot contained a stand of seeded timothy which was preceded by a couch grass-wheat hybrid. The timothy sod was quite pure. Only one-tenth of the dried sample contained weeds. Sampling techniques above and below ground were identical to those employed in the meadows. The survey of the organic material in the natural meadow and seeded timothy field was made over a period of three years,—1954, 1955, and 1956.

The third plot contained Sudan grass, with isolated patches of mint and buckwheat. Data on the yield of Sudan grass are given for one year only (1954), since the yields of subsequent years (1955 and 1956) varied widely because of excessively wet conditions. In 1954 the yield of Sudan grass was very high and at the beginning of July when the sample was taken after the first cutting, the stubble was already 50 to 60 cm. high. The roots were measured only in the 0 to 25 cm. layer, because only isolated rootlets extend below this depth.

Plant counts were made in all years during the period of full bloom of the meadow immediately prior to hay-cutting. Sampling time varied with the year, depending on the duration of high-water. Generally, the difference was never more than seven to eight days over the three-year period. In order to obtain a better estimate of the plant organic material associated with the processes of enrichment of bottom-land soil by nutrients and organic matter, a record was made of the second growth in the meadow and the timothy field at the end of the growing season late in October 1957. It included both the vegetation and roots.

TABLE 1

Crop yield on flood plain soils

Arable	Weight of air-dried material, centner/hectare			
	Vegetation Above-ground	Roots		
		Layer 0–25 cm.	Layer 25–50 cm.	Total
Timothy-fescue meadow; 1954	56.64	123.88	12.40	136.28
Timothy-fescue meadow; 1955	45.40	136.70	8.00	145.60
Timothy-fescue meadow; 1956	49.00	169.3	8.50	177.80
Timothy, seeded; 1954	60.63	101.52	1.28	102.80
Timothy, seeded; 1955	39.70	119.50	3.50	123.00
Timothy, seeded; 1956	45.00	120.0	9.6	129.60
Sudan grass; 1954	65.50	49.04	—	49.04
Aftermath of natural meadow; October 1957	13.7	153.0		153.0
Aftermath of seeded Timothy; October 1957	12.35			110.0

Data of plant yields are given in Table 1 and permit the following conclusions:

1) It is established that on the flood plain soils, the maximum amount of vegetative matter will be attributed to the root mass. This is in complete agreement with research reported elsewhere (5, 7). As a rule, the root systems have to 3.5 times more mass than the top portion of vegetation; 2) in different years the yield of various plant parts may vary greatly. For cultivated timothy, for example, the fluctuating varied between 39.7 and 60.63 cntr./ha. Considerably less fluctuation is noted in the natural meadow (45 to 56 cntr./ha.). It is assumed that these differences are due, first of all, to weather conditions. In 1955, for example, late floods and extensive silt deposition retarded the growth and development of plants on all arable land and the lowest yields were obtained in that year. Our observations indicated that in estimating crop yields samples taken over a single year are inadequate. Good crop yields on flood plain soils were obtained with Sudan grass. With favorable climatic conditions the weight of the aftermath after the first cutting at the beginning of the month of July was 65.5 cntr./ha. of hay; 3) the study of the root systems and their evaluation on a weight basis showed that roots were distributed primarily in the 0 to 25 cm. layer. At a 50 cm. depth, there was a sharp decrease in plant material and only isolated roots were found at that depth; 4) the autumn estimate of the vegetation above-ground in the natural meadow and the seeded timothy indicated that a substantial aftermath takes place under the snow, amounting to 12 to 13 cntr./ha. It is clearly evident that this remaining vegetation undergoes further mineralization and, combined with dead roots, is the source of supply of inorganic nutrients and nitrogen in the soils. After the removal of crops by man, autumn observations permit more effective evaluation of the extent of the biological cycle beneath the grass cover, not only in flood plain soils but also under watershed conditions.

To determine the extent of the biological cycle of individual nutrients, it is necessary to know both the mass of the vegetation and its qualitative composition. All sorts of plants taken from different arable areas were analyzed. The analyses were made on the dried matter by digestion with strong nitric acid and the addition of purified hydrogen peroxide. Results of the analyses were

TABLE 2

Nitrogen and ash contents of grass vegetation, in % of plants dried at 100° C.

Arable land	Objects investigated	N	Si	Al	Fe	Mn	Ca	Mg	K	P	S
1955											
atural meadow	Grass	2.17	1.43	0.14	0.061	Trace	0.27	0.12	2.03	0.28	0.13
	Mixed grasses	2.39	0.71	0.13	0.032	"	0.90	0.21	3.42	0.45	0.22
	Roots	1.40	3.19	1.78	0.612	0.035	0.51	0.09	0.51	0.30	0.14
eeded Timothy	Timothy	1.66	1.46	0.17	0.033	Trace	0.28	0.17	1.64	0.30	0.05
	Admixtures (other grasses + mixed grasses)	1.85	0.97	0.32	0.039	"	0.63	0.19	2.93	0.41	0.19
	Roots	1.46	2.57	2.25	0.603	0.028	0.55	0.18	0.74	0.38	0.09
eeded Sudan grass	Sudan grass	1.71	1.70	0.095	0.044	Trace	0.43	0.11	1.35	0.21	0.08
	Roots	1.15	1.49	0.50	0.133	0.01	0.34	0.04	0.69	0.14	0.04
1956											
atural meadow	Grasses	1.96	1.41	0.072	0.045	0.005	0.26	0.22	2.52	0.36	0.13
	Mixed grasses	2.11	0.44	0.089	0.076	0.008	1.00	0.40	3.47	0.57	0.22
	Roots from 0–25 cm.	1.51	1.71	2.04	1.08	0.064	0.53	0.22	0.79	0.38	0.14
	Roots from 25–50 cm.	1.32	2.30	3.64	0.95	0.050	0.52	0.12	0.79	0.21	—
eeded Timothy	Timothy (Above-ground portion)	1.62	1.15	0.078	0.025	0.001	0.22	0.16	2.35	0.25	0.05
	Roots from 25–50 cm.	1.40	1.37	2.05	0 35	0.021	0.32	0.25	0.89	0.27	0.09
	Roots from 25–50 cm.	1.24	1.53	3.39	0.61	0.019	0.33	0.18	0.98	0.20	—
fter second cutting 1957	Natural meadow	1.82	2.93	0.31	0.13	0.005	0.43	0.20	2.42	0.29	—
	Roots	1.36	1.70	3.85	0.47	0.015	0.38	0.23	1.31	0.19	—
	Seeded Timothy	1.58	2.50	0.52	0.11	0.003	0.29	0.21	2.17	0.25	—

xpressed in elements. Ash analyses of various roups of plants were repeated each year.

According to the analytical data (Table 2), ndividual species of meadow vegetations (tall nd "mixed grasses") differ widely in their hemical composition. For instance, the tall rass groups contain a higher silica content, while he "mixed grasses" group is higher in potassium, alcium, phosphorus, and sulfur. On the whole, lants of both groups are characterized by a high ontent of nitrogen and potassium (more than %). The above-ground portions of plants are nvariably high in potassium, nitrogen, silica and alcium. Bazilevich (2) arrived at a similar conlusion. Plant root systems contain a fairly large mount of silica, aluminum, iron, and (unoubtedly of considerable interest) substantial mounts of manganese, an element that is completely lacking in above-ground vegetation. Conomitantly, there is a sharp decrease in potassium n the roots but an increase in calcium. This is articularly conspicuous when compared with he content of the above-ground portion of ereals.

We conclude that the chemical composition of different plant groups with respect to year is quite constant, even though individual elements fluctuate considerably with the season. Thus, the analysis of the aftermath in October, showed that at the end of the growing season there was a sharp increase in silica, aluminum, and iron in the tops, and a clearly evident decrease of potassium in the root systems. Consequently, in the autumn and spring, because of the mineralization of plant material, significantly larger amounts of silica, aluminum, and iron are deposited in the soil than can be accounted for during the blooming period. Therefore, the amount of regrowth after the harvest must be considered.

From the chemical composition data and estimates of yields we can easily evaluate and estimate not only the amount of single nutrients in various parts of plants but also the extent of the requirement and return to the soil of mineral elements and nitrogen during the annual cycle of soil formation. These calculations are given in Tables 3 and 4.

Our findings show that the highest concentra-

TABLE 3

Accumulation of nitrogen and minerals in the grass vegetation of flood plain soils, kg./ha.

Arable land	Part of plant	Weight of absolutely dry-material cntr./ha.	N	Si	Al	Fe	Mn	Ca	Mg	K	P	S	Total
Natural meadow; 1955	Tops	41.9	91.53	57.89	6.23	2.42	—	13.07	5.27	88.94	12.20	5.69	283.2
	Root	135.3	189.42	431.60	240.83	82.80	4.73	69.00	12.17	69.00	40.59	18.94	1159.0
Natural meadow; 1956	Tops	45.2	89.04	60.82	3.29	2.12	0.23	13.97	10.48	116.75	16.90	6.08	319.68
	Roots	160.9	222.95	273.53	328.23	183.77	10.29	85.27	35.40	128.72	61.14	22.52	1351.82
Timothy; 1955	Tops	36.7	61.62	51.76	6.79	1.14	—	11.57	6.31	64.96	11.41	2.35	217.91
	Roots	113.6	165.85	292.0	255.60	68.16	3.40	62.48	21.44	84.06	43.16	10.22	1006.37
Timothy; 1956	Tops	39.2	64.35	44.40	4.02	0.85	0.03	10.14	6.38	94.26	10.38	2.47	242.25
	Roots	115.3	161.42	160.0	236.36	40.35	2.30	36.89	28.82	103.77	31.13	10.37	811.41
Sudan grass; 1955	Tops	60.48	103.42	103.40	6.04	2.41	—	26.00	6.65	81.64	12.70	4.83	347.00
	Roots	45.3	52.09	67.49	22.65	5.88	0.45	15.40	1.81	31.25	6.34	1.81	205.17
Natural meadow; 1957	Aftermath	12.0	21.84	35.16	3.72	1.56	0.06	5.16	2.40	25.04	3.48	1.56	99.98
	Roots	140.9	191.62	239.53	542.46	66.22	2.11	53.54	32.40	183.17	26.77	19.72	1357.54
Timothy; 1957	Aftermath	11.02	17.41	27.55	5.73	1.21	0.03	3.19	2.31	23.91	2.75	0.55	84.64
	Roots (3-year-average)	110.0											Average 900

TABLE 4

The balance of nitrogen and minerals substances in the vegetation of flood plain soils, kg./ha. of absolutely dry matter

Arable Land	Total	N	Si	Al	Fe	Ca	K	P	S
Removed with cropping									
Natural meadow	294	90	60	6	2	13	103	14	6
Timothy	226	65	50	6	1	11	80	10	3
Sudan grass	334	more than 100	more than 100	6	2	26	81	13	5
Returned to soil									
Natural meadow	505	92	148	99	45	30	63	20	8
Timothy	375	71	100	87	19	25	54	15	4
Sudan grass	293	70	100	26	7	20	55	13	2
Remained in roots									
Natural meadow	812	137	235	190	86	51	66	33	14
Timothy	583	109	150	163	36	33	62	24	6

tion of chemical elements, relative to the largest plant mass, occurs in the root systems. The highest concentration was observed in the roots of the natural timothy-fescue meadow (1159.0 to 1457.0 kg./ha.), the lowest, in the roots of Sudan grass (205.0 kg./ha.). Their concentration in the plant tops is generally three to four times less than in the roots. In natural meadows this quantity is 280 to 320 kg./ha., while in seeded timothy it is 217 to 240 kg./ha. Sudan grass appears to be an exception. Above-ground portions have a higher content of elements (about 350 kg./ha.) than do the roots.

In the non-mowed meadows the amount of matter concentrated in the upper portion of plants, appears to balance the requirement and return to the soil of nitrogen and nutrients released by the mineralization of the below-ground portion of plant remains.

The quantity of nutrients removed from the soil by harvesting is higher than our results indicate because we show only that portion of nutrients concentrated in the tops before the first utting. For productive purposes two crops are sually harvested from the well-developed flood lain meadows and the fields of perennial and nnual grasses. Thus the amount removed should crease two and one-half times. The return to he soil would take place through decomposition f the aftermath which contains sufficiently large uantities of plant nutrients, and by mineraliza-on of a definite portion of the root systems.

Kovda (3) and Bazilevich (2), have both as-umed that only one-third of the root systems of erennial grasses die each year, and that only ne-third of the nutrients in the root systems re-urned to the soil annually by mineralization. hese quantities will be considered in determin-ng the extent of the biological cycle (see Table).

Although under the conditions studied, 900 to ,450 kg./ha. of the various minerals and nitrogen are withdrawn under snow and assimilated y the aftermath and root systems, only 400 to 550 kg./ha. are released during mineralization. Sudan grass, an annual crop, has the smallest returns of nutrients (about 300 kg./ha.) despite complete mineralization of the entire root tissue.

Data in Table 3 show that in terms of a one-hectare area and maximum crop, silica (up to 490 kg./ha.), nitrogen (up to 312 kg./ha.), aluminum (up to 330 kg./ha.), potassium (up to 245 kg./ha.), and iron and calcium, are generally accumulated. Plant tops show a considerable accumulation of potassium, while larger concentrations of silica, aluminum, nitrogen, and sometimes iron occur in the roots. The high content of silica and aluminum in plants indicates not only their "forced" absorption from soil because of their abundance, but also the degree of their availability. It is perfectly clear that present soil formation in the flood plain of rivers of the sod-podzol zone takes place with considerable involvement of the biological cycle, not only in terms of "inert" elements such as silica and aluminum, coming in from the watershed basin, but also from their "activation" by a biological agent from the flood plain alluvium. Vegetation undoubtedly plays an important role in the "activation" of silica and aluminum. From this viewpoint it is possible to explain the presence of a light silica powder, sometimes appearing on the structural contacts lines as a process of biological separation of silica in sod-meadow soils, not as a remnant of a former forest on these soils.

Aydinyan's statement (1) that the fine, dispersed portion of chernozems are biogenic in origin is also true to some degree of flood plain soils. Evidently, a significant amount of silicic acid and oxides released from mineralization of plant remains, contribute still more to the synthesis of secondary minerals in sod-meadow soils. This problem, however, requires special investigation.

Comparison of findings typical of nutrient withdrawal from soils by harvesting of grasses and their return to the soil by the decomposition of plant remains, shows clearly that annual balance is in favor of the return of nutrients. So, for example, a single harvesting of natural meadow removes on the average 300 kg./ha. of nutrients, whereas, on the average, an equivalent of 505 kg./ha. is returned to the soil. In the case of timothy, removal amounts to 225, and the return, 375 kg./ha. With a Sudan grass cover, the removal is greater than the return, 334 against 293 kg./ha. Similar findings are reported by Kovda (3).

When two crops are cut, the amount removed should increase two and one-half times, so that in natural meadow and perennial seeded grasses it almost equals the amount of elements returned to the soil or approaches a negative quantity. It is evident from Table 4 that the return of various elements to the soil takes place in terms of silica, aluminum, iron, and calcium. Nitrogen, phosphorus, and sulfur barely maintain a positive balance with a single harvesting, but show a negative balance with a double cutting. Potassium evidently has a negative balance, because its removal by harvesting is greater than its return to the soil. This means that potassium fertilizers must be added to flood plain soils, particularly when they are planted to crops. Periodical deposition of silt cannot compensate for the deficiency of this element in flood plain soils. Observations over several years have shown that live roots annually retain a substantial amount of nutrients (up to 812 kg./ha. under natural meadows).

Conclusions

1. It is established that where soil conditions are equal, the largest mass of plant matter is produced on natural, tall-grass meadows. The accumulation of organic matter is derived from the root systems. Restoration of soil organic

matter and nutrients removed by harvesting is brought about by the mineralization of the aftermath and decomposition of roots.

2. The ash composition of plants from the timothy-fescue meadow is similar to that of seeded grasses. Generally, there is a high percentage of nitrogen, potassium, silica, and calcium in the plant tops. Roots are characterized by high concentration of nitrogen, silica, aluminum, and iron. A considerable amount of manganese is observed only in the roots.

3. The rate and extent of the biological cycle on the flood plain does not depend solely on the yield, but also on the amount of plant matter removed. The overall annual balance of mineral substances and nitrogen under perennial crops points favorably to the return of nutrients to the soil. A negative balance is obtained in the case of Sudan grass.

4. The return of nutrients to the soil occurs for the most part in terms of silica, aluminum, iron, and calcium. In respect to organic genesis, (nitrogen, phosphorus, sulfur, and particularly potassium) a negative balance is obtained. This is distinctly demonstrated when the annual crops are harvested more than once. In this connection, the problem of the need to add potassium fertilizers on the sod-meadow soils arises, particularly when cultivation is started.

5. A greater concentration in roots of such inert elements as silica and aluminum, and sometimes iron, reveals the high degree of their ava ability and their significant role in the soil-for ing processes on the flood plain.

6. It is recommended that perennial grasses introduced into the crop rotation plan for i tensive cultivation of plowed intertilled crops flood plain soils.

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HE NATURE OF GAS AND VAPOR TRANSFER IN SOIL IATERIALS

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THE mixture of gases and vapors, called soil air forms, moves under quite different condions in soil materials than in the atmosphere here the gas-vapor mixture is entirely free of ntact with solid and liquid surfaces. Conditions lso differ from those in water, in which the gasapor mixture is held in the dissolved or abrbed state. Since the dynamics of gases and apors reach to great depths, we deem it necesary to consider "soil materials" instead of soils."

There are laws governing the dynamics of air, he gaseous mixture of the atmosphere, its flow, hanges in composition, temperature, pressure nd so on. The relationships of convective circution in the atmosphere have been revealed on he basis of a very important rule—Bernoulli's rinciple of continuous flow. Thus, the hydroynamic laws (2, 10) are applied to the dynamics f gas mixtures in the atmosphere.

For the gaseous mixture in soil materials, nalogous relationships have been and are being sed, at times, in which all transfer of gases and apors is explained by convective air flow in soil aterials (6, 9). But, as shown in special investiations on the dynamics of carbon dioxide and xygen in the soil profile, which we conducted nder various conditions from 1945 to 1955, the henomenon of convective flow is not observed in oil materials (22, 25). We believe this is because oil materials are a special medium for gas mixures, in which gas and vapor transfer operates nder entirely different laws from the standard nes for the atmosphere and hydrosphere. Soil aterials have a system of fine pores and intertices, a large surface interaction, and a rather table temperature gradient with depth.

In modern physics the thermodynamic and nolecular kinetic properties of gases and their nixtures are determined for two conditions: a) rdinary—at atmospheric pressure with colliion and molecular interactions, gases comply vith known hydrodynamic laws; b) rarefied—at ery low pressures with few collisions and molecular interactions, gases do not comply with known hydrodynamic laws.

The limits of these two conditions are determined by the distance of free path for molecules of the given gas or mixture. The gas is in the ordinary condition if the amount of space available to each gas molecule is greater than the molecular distance of free path, and in the rarefied condition if the amount of space is equal to or less than the distance of molecular free path (1, 5, 15, 18, 25, 26). The mean distance of free path for atmospheric gas molecules is ordinarily 10^{-5} cm.

Most porous solids, including soil materials, especially below the plow layer, have pore sizes of the order of 10^{-5} to 10^{-7} cm.[1] In such pores, gas molecules are in the rarefied condition, notwithstanding the fact that the system is in contact with the atmosphere, and the gases are at atmospheric pressure (1, 15).

Thus, according to modern physics, chemistry, and geology, soil materials belong to those systems providing a rarefied condition of gases and vapors in its pores and interstices. It follows that any gas or vapor, passing from the atmosphere (or other medium) into soil material, automatically and simultaneously passes from the ordinary to the rarefied condition with a corresponding change in its thermodynamic and molecular kinetic properties.

From Table 1 it is seen that gas and vapor molecules travel at very great speeds, exceeding those familiar in technology. The free path of gas molecules between collisions is longer than their diameter and the pore diameter of many sorbents. The diameter of gas and vapor molecules (10^{-8} cm.) is smaller than the diameter of soil pores (10^{-3}–10^{-5} cm.), which allows them to enter and move in the mass of soil material.

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[1] (page 89) Experiments on counter effusion of CO_2 and O_2 have been carried out in fine porous ceramics as well as in canals with $d = 1.2 - 2.0$ mm. They showed that rarefied gas phenomena are observed even in larger pores and interstices. The differences are only in magnitude and speed.

TABLE 1

Basic molecular characteristics of several gases at 0° C and atmospheric pressure

Gas	Molecular diameter, cm.	Molecular velocity, meters per sec.	Molecular mean free path, cm. λ	Molecular collisions per sec. per $cm.^3$ (in the atmosphere)	Throttling effect upon leaving a small orifice at 1 atm., degrees[a]
H_2	2.17×10^{-8}	1838.0	17.8×10^{-5}	10330×10^6	−0.031
O_2	2.71×10^{-8}	461.0	10.2×10^{-5}	4520×10^6	+0.335
N_2	2.95×10^{-8}	493.0	9.5×10^{-5}	5190×10^6	+0.319
CO_2	2.90×10^{-8}	393.0	6.5×10^{-5}	6050×10^6	+1.352
N_2O	3.33×10^{-8}	393.0	6.5×10^{-6}	6050×10^6	—
H_2O	2.27×10^{-8}	615.0	7.2×10^{-6}	8540×10^6	—

[a] Temperature change for 1 atm. drop in pressure with gases under pressure.

Upon leaving a small orifice (pore) hydrogen molecules gain heat; oxygen and nitrogen molecules lose it, and carbon dioxide molecules lose even more heat. From this we may conclude that carbon dioxide moving through a porous medium will always decrease its molecular speed. A continuous heat supply along the path followed by the molecule is required to maintain the speed of CO_2 movement.

Hydrogen molecules (and apparently water vapor) require constant heat removal along the path of the molecules in order to maintain a constant speed. Nitrogen and oxygen molecules occupy an intermediate position. Their movement is determined by that of CO_2 and H_2O molecules, which have more affinity for the surfaces of soil particles (14, 15, 22).

It is known that gases passing through a porous diaphragm change in composition even at constant temperature (27). This phenomenon is called atmolysis and is used for separating isotopes of elements. Dyufor (27) mentioned that when two gases diffuse through a porous diaphragm from opposite sides, the temperatures of the diaphragm surfaces change. The surface warms up where the lighter gas enters and the heavier gas leaves, and the other surface cools off (Fig. 1, part I). Federsen (27) confirmed the opposite phenomenon: upon warming or cooling one of the surfaces of a porous diaphragm, one of the gases moves to the warmer side. He called this phenomenon thermal diffusion (8, 27).

From recent work on isotope separation it is known that two gases located in two cavities connected by a canal 1 to 5 mm. in diameter will flow past one another under the influence of temperature gradient (1, 8, 15, 22, 28). At c dinary pressures a considerable countercurre arises and molecules are almost completely tran ferred from one cavity to the other. The presen of the so-called molecular convection naturall assumes a certain canal size. This method c separating gaseous isotopes is called the therm diffusion method (8, 28).

In porous materials a phenomenon called e fusion is observed which is the spontaneous di charge of gas molecules from pores or sma orifices (15, 26). Two types of effusion are d scribed in modern physics courses: isothermal an non-isothermal, proceeding under the influence c a temperature gradient. The elementary proces of effusion consists of flow across the boundary c two closed volumes, separated by one or mor small orifices, the diameter of which is equal t or less than the distance of free path of the ga or vapor molecules.

Two or more gases in adjacent volumes joine by orifices or pores will show counter effusion which proceeds intensively at uniform temperature until the partial pressures of the gases in al volumes are equal. With temperature gradients the partial pressures of the gases do not equalize but some of the gases have higher concentrations in the regions of higher temperature. The gases in a mixture are distributed along the temperature gradient according to their properties and the surface properties of the volume. Usually heavier gases move to regions of higher temperature and lighter gases counter effuse to regions of lower temperature (15, 22).

Equilibrium in counter effusion occurs when an equal number of molecules of all gases pass in both directions at strictly equal velocities through each canal or pore (15, 22, 26) (Fig. 1, part III).

In all cases of effusion the gas molecules move without collisions.[2] The speed of molecular transfer is much greater than the speed of ordinary diffusion; 50 times according to experiments o G. Brown (in plant leaves), and approximately 7 times according to our experiments (in ceramics Table 5) (20, 22).

In previous articles (23, 25) we have described

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[2] Three dimensional movement of gases in the soil mass is not excluded, but the prevalence of directed gas movement along a clearly developed temperature gradient (thermal effusion) is meant.

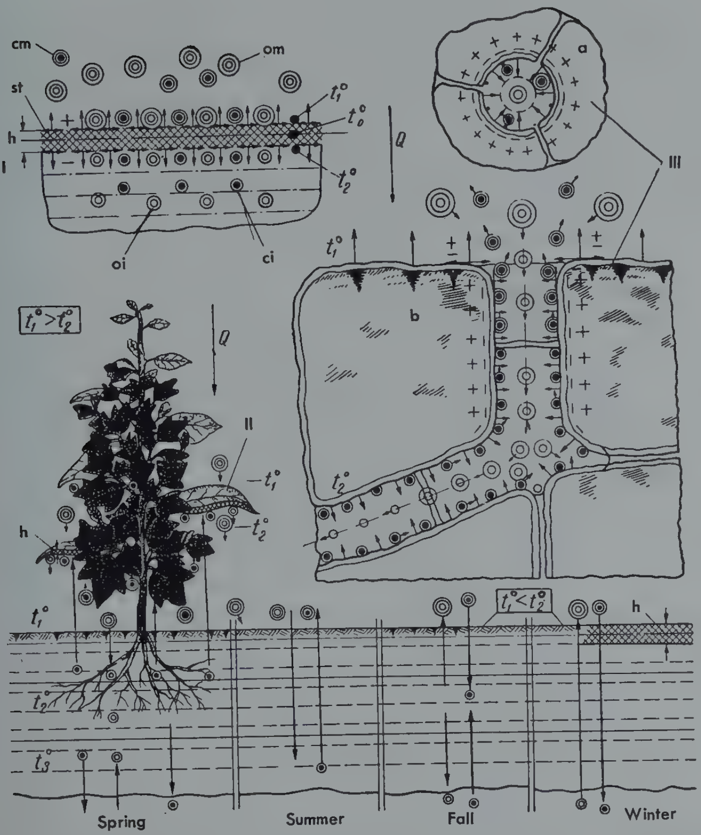

FIG. 1.—Diagram of CO_2 and O_2 counter effusion in soil materials: I—elementary porous diaphragm; II—soil—plant system; III—Cross section of a soil pore (horizontal [a] and vertical [b]); Q—direction of solar radiation; $t^0_{1.2.3}$—different temperatures; h—diaphragm thickness; st—surface tension; cm—carbon dioxide molecule; om—oxygen molecule; ci—carbon dioxide ion; oi—oxygen ion.

he typical temperature regimes of soil materials howing a stable temperature gradient through he profile for most of the year.

From the surface of the soil material to the ine of constant daily temperature it is difficult to ind a layer of soil with uniform temperature; ariations are always observed. Whereas in the tmosphere the temperature gradient per meter f height may be less than 0.06°, in the soil maerial it reaches 60° in the summer, or 1000 times greater. It follows that the effect of temperature gradient on gaseous molecules is correspondingly greater. Viewing the soil material profile as an nfinite number of fine porous diaphragms (similar to plant leaves), laid on top of each other so hat the temperature of their adjacent walls is the same, we may with good reason apply the laws of gas transfer in porous media under the influence of temperature gradients (Fig. 1, part II).

Since gases in porous media occur in a rarefied condition strongly influenced by surface forces, and the temperature of a gas is one of its fundamental characteristics, we observe in the soil material profile: a) laminar arrangement of gas mixtures; b) the phenomenon of sorption, with higher than atmospheric concentrations of gases having great affinity for soil material surfaces; c) continuous spatial transfer of gaseous molecules with vertical transfer under the influence of temperature gradients prevailing.

From the conditions of thermal diffusion and their physical nature, soil materials are expected to exhibit the isothermal and non-isothermal counter effusion of gases and vapors. This is confirmed by observations on gaseous exchange in soil materials and the special experiments described below. In thick porous bodies, including soil materials, counter diffusion of gases may be considered as an effusion process, consisting of a series of elementary counter effusions[3] of two or more gases, proceeding in individual pores. An exception is the plow layer of soil where interstices between soil particles exceed the molecular free path, and other processes may take place, such as; thermal diffusion, compression and expansion of gases, convective currents depending on daily temperature inversions, ordinary diffusion and so on. For brevity, we will call nonisothermal effusion—thermal effusion, and counter diffusion of gases and vapors in soil materials accordingly—counter thermal effusion, always combined, naturally, with processes of sorption (25).

We will discuss some research on the dynamics of two essential gases, CO_2 and O_2, in soil materials, utilizing the new theoretical concepts applicable to porous media. We carried out the basic experiments on continuous abandoned lands and black fallow on the experimental fields of the Timiryazev Agricultural Academy. Soil air samples were taken and analyzed over a period of one year. Systematic measurements of temperature by soil depths showed that the line of constant daily temperature was found mostly at depths of 80 to 120 cm. This depth frequently coincides with the upper edge of capillary ground water.

Thus, the experimental fields of the Timiryazev Agricultural Academy present an excellent model of soil materials with sharply contrasting surface conditions (abandoned land and continuous fallow), on which basic questions of gas dynamics may be decided experimentally, in order to verify later the results and conclusions with other materials under other soil and climatic conditions. Definite areas of 1 to 2 sq. meters were sampled in three replications (22).

First, attention was turned to the stability of the layer composition of the gaseous mixture in soil materials. The soil material was removed to a depth of 120 cm. with a soil auger, and the hole was filled with pure quartz sand. During a day, the analysis of samples in every hole and contr gave consistent results. Later, 3.5 l. of soil a was pumped out continuously from a point 2 cm. deep, but its content of CO_2 and O_2 did no change (0.30% CO_2). Similarly, air was pumpe from a depth of 60 cm. for four hours from a poi on the meadow, but its composition did n change. Both the first and last samples containe 1.2% CO_2.

These facts testify that the layer compositio of gaseous mixtures in soil materials does no depend on properties of the soil horizon, on possible pressure changes with depth, or on th penetration of atmospheric air into the depths But the layer composition slowly changes durin the year, acquiring opposite tendencies in ga concentration in different periods. Such composition is seen in Table 2 which considers the yearl dynamics of CO_2 and O_2 in soil materials. Th data indicate slow changes in the concentration of CO_2 during the year and low concentrations of CO_2 under fallow.

Since the difference in CO_2 concentration with and without plant cover was explained by the excretion of CO_2 from plant roots, an experiment was established to explain the role of plant cover on abandoned land. It was continued three days, with the following plots: control, with grass, and with grass removed leaving the living roots. The CO_2 absorption by roots and excretion by leaves of plants must also be considered (3, 19, 22).

It follows from Table 3 that the lower CO_2 concentration in soil air from the plot with grass removed depends on heating and a large difference in temperature between soil layers. The higher CO_2 concentration under grass depends not as much on root excretions as on the shading of soil, which absorbs up to 40% of the solar radiation. Characteristically, the table shows a gradual migration of CO_2 from lower to upper layers and then to the atmosphere. Thus, the lowering of CO_2 concentration on the warmer plot depends on stronger diffusion of CO_2 into the atmosphere and of O_2 from the atmosphere into the soil.

From the data in Table 3, considering the predominance of warming over nocturnal cooling of the soil profile (nocturnal minima exceeded 16°), and thus, the predominance of CO_2 desorption and effusion into the atmosphere, the thermal effusion of CO_2 (Fig. 2) was plotted. The curve shows the quantity of CO_2 evolved (effused)

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[3] Or thermal diffusions (27).

TABLE 2

Seasonal variations in the percentage composition of soil air as affected by temperature differences

epth, cm.	Abandoned land								Fallow land			
	August 22, 1946		March 12, 1947		April 30, 1947		July 1, 1947		May 12, 1947		Sept. 8, 1947	
	Temperature, °C.	CO_2	Temperature, °C	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2
10	16.2	0.65	−0.4	−0.18	8.8	2.30	14.5	0.70	16	0.16	13.9	0.08
20	14.4	1.15	−0.2	0.18	7.8	2.45	15.0	1.35	9.2	0.11	13.0	0.22
30	—	—	±0.0	0.38	9.1	2.00	—	—	—	—	—	—
40	14.0	0.70	+0.2	0.42	5.6	0.95	14.2	1.50	7.6	0.40	12.4	0.16
60	13.5	1.55	0.4	0.50	5.2	0.44	13.6	1.65	—	—	—	—
80	13.8	1.00	0.8	0.65	4.8	0.46	12.8	2.70	6.4	0.38	12.3	0.18
100	13.6	0.84	1.1	1.50	3.4	0.60	12.3	1.52	—	—	—	—
120	13.4	0.50	1.2	1.70	—	Water	—	—	—	—	—	—

TABLE 3

Percentage CO_2 concentration as affected by soil temperature and temperature gradient at various times

Depth, cm.	June 25		June 26				June 27				June 28, 1947			
	Initial data		With cover		Without cover		With cover		Without cover		With cover		Without cover	
	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2	Temperature, °C.	CO_2
0–3	20.0	0.08	22.2	0.05	33.1	0.15	22.5	0.10	30.5	0.08	13.0	0.05	16.9	0.06
10	18.3	1.10	20.2	1.20	23.2	2.90	21.0	2.00	24.8	0.60	14.5	0.70	18.0	0.90
20	16.4	2.50	18.4	2.90	21.8	3.50	19.6	3.30	23.8	1.60	15.0	1.35	17.0	1.10
40	14.0	3.40	15.2	3.75	16.4	3.90	16.4	3.70	17.2	2.51	14.2	1.60	15.0	1.50
80	12.8	3.30	13.3	3.70	14.0	3.93	14.6	3.40	15.0	3.50	13.8	2.70	13.1	1.50
100	12.6	Water	12.8	Water	13.0	Water	13.5	—	13.8	—	12.3	2.52	12.5	1.70

Note: At 15:30 on June 27, in connection with a small thunderstorm, the temperature fell from 31 to 3° C. and the coolness lasted until the morning of June 28.

rom the soil without grass on the warmer plot, ompared with the control having grass cover and ess warming. On the abscissa are given absolute emperatures and temperature differences beween layers of soil from 0 to 100 cm. It follows rom the graph that lowering of CO_2 concentraion with soil warming is proportional to the emperature differences between the soil layers nvestigated, since the control had a higher conentration which changed very little.

The mechanism of CO_2 and O_2 transfer under he influence of temperature differences may be evealed only by experimentally establishing temerature gradients, which were achieved in vessels oined by capillaries.

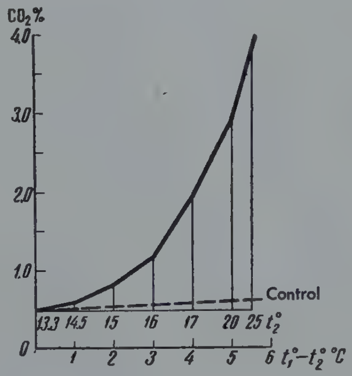

FIG. 2.—Thermal effusion curve for CO_2 .

TABLE 4

Displacement of CO_2 and O_2 concentrations in connected vessels under the influence of a temperature gradient

Vessel temperatures		Reaction time, min.	Air composition, volume %							
			Before experiment				After experiment			
			1st vessel		2nd vessel		1st vessel		2nd vessel	
			CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
Paried vessels with homogenous gas mixture										
+5.0	+15.0	15.0	4.00	15.60	4.00	15.60	3.60	16.00	4.40	15.20
Same, with a longer reaction time										
+5.0	+15.0	30.0	4.00	15.60	4.00	15.60	2.80	16.80	5.20	14.40
Three vessles, cooled atmospheric air in the middle one, (ends have 14°C.)										
+4.0	+14.0	30.0	4.00	15.60	4.00	15.60	4.00	15.60	4.00	15.60
Paired vessels, atmospheric air in the first, cooled soil air in the second										
+14.0	+4.0	30.0	0.05	20.80	3.60	16.00	0.50	20.35	0.15	16.45
Paired vessels with soil air, filled with sand										
+18.0	+22.5	30.0	4.00	15.60	4.00	15.60	1.60	18.00	6.40	15.2

TABLE 5

Direction and rate of thermal effusion of CO_2 and O_2 in a porous medium

Temperatures of cylinder walls, °C.		Time of contact with vessel, sec.	Air composition in cylinder, %		Time of heating or cooling, min.
Outer	Inner		CO_2	O_2	
22.0	22.0	5.0	0.03	20.9	—
34.0	40.0	5.0	1.80	19.0	10/2
Same	Same	0.0	1.52	19.4	6/2
40.0	36.0	0.0	0.00	20.9	7/2 cooled
35.0	40.0	3.0	1.65	19.3	7/2
40.0	37.0	0.0	0.00	20.9	5/2
36.0	42.0	1.0	1.50	19.4	8/3
40.0	36.0	0.0	0.00	20.9	5/3
36.0	34.0	0.0	0.00	20.9	Cooled
22.0	22.0	1.0	0.04	20.9	"

Table 4 shows the concentration of gases by counter thermal effusion under the influence of a steady temperature gradient. In moving, CO_2 and O_2 change places, volume for volume, maintaining the sum of the concentrations in the vessels. Maintaining the continuous temperature gradient facilitates directed gas transfer ove great distances; breaking the gradient stops th transfer. A porous medium speeds gas counter flow. The results obtained are not in any way characteristic of ordinary diffusion, which occur under partial pressure differences at constant temperature. Hence, even in upper soil layer diffusion takes place locally depending on temperature differences,—thermal diffusion[4]; in lowe layers thermal effusion or counter thermal effusion.

We determined the speed of counter therma effusion in a porous medium using a porous hollow cylinder[5] with a glass tube for withdrawing an air sample from it. Wall temperatures of the cylinder were measured with built-in thermocouples, connected with galvanometers. The wal thickness of the cylinder was about 8 mm. (The cylinder was of the Chamberlain filter type.).

After a preliminary heating to 150° for evacuating sorbed gases from its pores, the cooled cylinder was placed into a vessel with soil over which a constant atmosphere was maintained. The temperature regime of the cylinder and its time of contact with air in the vessel was varied. Other conditions were constant. The initial data were: a) cylinder t = 22°C.; CO_2 = 0.025%; O_2 = 20.9%; b) vessel t = 22°C.; CO_2 = 1.6%; O_2 = 19.3%. The results (Table 5) show that no gas transfer was observed during these contact times with the cylinder walls and vessel at the same temperature. With temperature differences between the cylinder and the surrounding medium, two cases of gas transfer are possible: a) temperature of the outer wall lower than that of the inner—CO_2 moves into the cylinder, O_2 outward; b) temperature of the outer wall higher than that of the inner—CO_2 moves outward, O_2 inward. Gas transfer is complete in less than one second at temperatures near to the maximum for soil masses. The actual time was not given by this method. Since the interior cavity of the cylinder contacted the air in the vessel only through pores in the wall, we conclude that the gases moved counter to each other—by counter thermal effusion.

Gases and vapors in soil materials interact with the solid and liquid phases. Therefore there are always two forms of gas-vapor mixtures in soil aterials: 1) that adsorbed by its solid and liquid hases and 2) the free mixture in interstices and pen pores (14, 22, 25). Both forms are always in mplex equilibrium with each other and the soil aterial surfaces, with the atmosphere and with e ground water (7, 13, 16, 22, 25) to some egree.

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[4] Dimensions of the capillaries are larger than the free path length of CO_2 and O_2 molecules.

[5] Dimensions of the pores are smaller than the free path length of CO_2 and O_2 molecules.

We determined the ratio of sorbed and free O_2 in podzolic soil material (Table 6) by analysis of gases (23, 24). At first, samples of the free gas mixture to a depth of 1 m. were taken into a pipette through a boring pipe. Later, soil samples were taken from the same horizons in a holding device with a Nekrasov auger. Soil temperature and moisture were determined. The holder with the soil was opened 30 minutes for the escape of free CO_2, then saturated with water for the displacement of the gas mixture, which was analyzed for CO_2 and O_2. Upon displacing air from samples of dry leaves, peat, manure, and other materials, a higher concentration of CO_2 in the displaced air was also confirmed (6, 22). It is also known that green leaves may adsorb and desorb gases, particularly CO_2, depending on light and temperature (3, 22). Hence, gas and vapor sorption by soils and plant cover accompanies their transfer in soil materials.

TABLE 6

ercentage of free and sorbed CO_2 in soil materials

Depth, cm.	Moisture % in soil material	Temperature °C.	Free CO_2		Sorbed CO_2		Sum of free and sorbed CO_2	Ratio of sorbed to free CO_2
			Initial state	After diffusion from sample	Natural state	Air dry state		
0–10	19.08	18.8	0.65	0.14	0.40	0.14	0.19	0.91
10–20	18.83	17.0	1.00	0.08	0.65	0.60	2.25	1.25
20–30	18.24	16.4	1.40	0.05	0.52	1.00	2.92	1.09
30–40	16.83	16.0	1.35	0.04	0.22	0.50	2.07	0.53
40–50	14.60	15.5	1.25	0.03	0.18	0.40	1.83	0.46
50–60	16.25	15.0	1.25	0.02	0.16	0.20	1.61	0.29
60–70	15.76	14.6	1.10	0.03	0.50	0.90	2.50	1.27
70–80	16.30	14.2	1.85	0.035	0.55	0.90	3.30	0.78
80–90	16.59	13.8	1.70	0.04	0.42	0.90	3.02	0.77
90–100	98.10	13.6	1.60	0.03	0.40	0.90	2.90	0.81

The foregoing premises and experimental results form the basis for the following explanation of the annual fluctuations in CO_2 and O_2 contents in soil materials (Figure 3).

Spring. The increase in soil surface temperature, as it penetrates into the soil depth, facilitates desorption of CO_2 adsorbed during the fall and winter and activates biochemical processes in the soil material. The temperature gradient

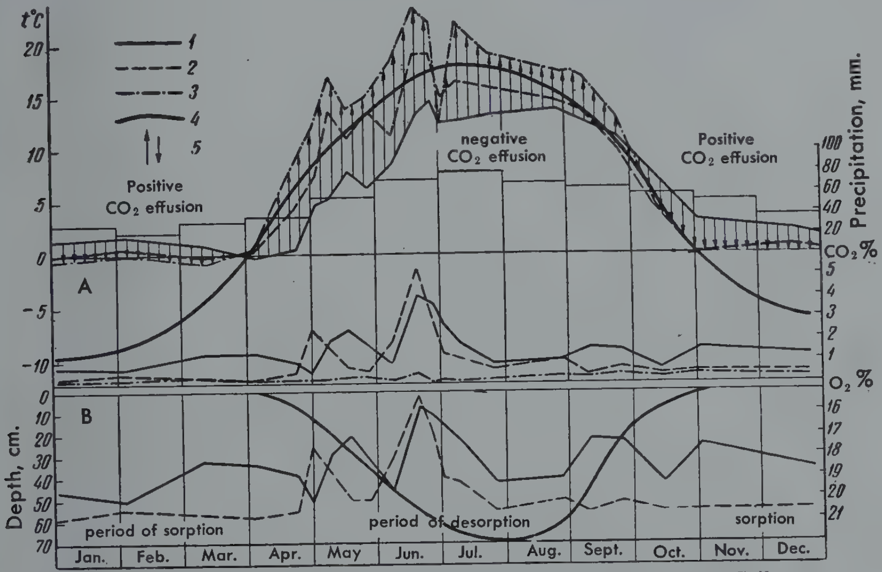

FIG. 3.—Annual cycles of CO_2 (A) and O_2 (B) in soil materials, 0–100 cm. Soil temperatures and gas concentrations: 1—for 80 cm. depth; 2—for 20 cm. depth; 3—for surface; 4—average air temperature (upper) and its penetration into the soil (lower); 5—amount and direction of temperature gradients.

also increases and embraces more of the soil material profile. The sign of the temperature gradient changes from winter to summer; thermal effusion increases gas effusion; CO_2 goes into the atmosphere; and O_2 moves into the soil, still further activating oxidizing processes. The spring maximum in the CO_2 curve and minimum in the O_2 curve set in (11, 22, 29, 30).

Summer. The temperature increase penetrates to the line of constant daily temperature and all easily sorbed CO_2 is desorbed from the warmed soil (period of desorption). The soil surface temperature and the temperature gradient in the soil material reach their summer maxima. Thermal effusion reaches a maximum, and the supply of free CO_2 is exhausted (negative CO_2 effusion). The summer minimum in the CO_2 curve and maximum in the O_2 curve set in.

Fall. The surface cools while the earlier temperatures are maintained deeper in the soil. Thermal effusion occurs in the soil material, but the exit of CO_2 to the atmosphere is hindered by development of a winter temperature gradient from the surface. The cooled surface layer absorbs CO_2 effused from lower layers. There occurs a second fall maximum in the CO_2 curve and some reduction in the O_2 content.

Winter. The temperature of the upper layer of soil material decreases, CO_2 sorption increases (period of sorption), and the winter temperature gradient rises. The soil temperature increases relatively with depth. Effusion of CO_2 into deep soil materials increases with little adsorption in the lower layers and the CO_2 concentration increases with depth (positive CO_2 effusion). Oxygen moves to the surface under the influence of the temperature gradient and is replaced by CO_2. The annual cycle of gas dynamics is completed. The driving forces of this cycle are the changing absolute temperatures and the periodic changes in the value and direction of the temperature gradient in soil materials. The absolute temperature regulates sorption and the temperature gradient regulates thermal effusion (14, 22, 23, 25, 26, 27, 28).

The described dynamics of CO_2 and O_2 correspond fully to the activities of microbial and plant root systems in the soil and green plant parts in the atmosphere: a higher level of biotic activity corresponds to greater CO_2 outflow from the soil into the atmosphere and O_2 inflow into the soil, a lower level of biotic activity corresponds to less CO_2 outflow and O_2 inflow. A diagram of the mechanism of counter effusion o gases in soil materials is given in Figure 1 (I and III).

The periodicity of the CO_2 and O_2 curves with sudden changes from maxima to minima or ordinates of the same magnitude, testifies to the presence of two connected processes—sorption and thermal effusion. The maxima correspond to increasing desorption with constant or decreasing effusion; the minima to constant or decreasing desorption with increasing effusion, changing to thermal effusion. The algebraic sums of the two counter processes give a broken curve describing the processes of gas exchange and photosynthesis in time (3, 4, 20, 22).

Work concerning the mechanism of water vapor movement in soil materials (12, 17, 21) showed recently that the principles of convection and heat transfer for the atmosphere did not explain the phenomena occurring in soil materials (2, 7, 10, 13, 17). A basic objection to possible condensation of vapors deep in the soil material, according to Folger's theory (7, 13), was (and still is) the absence of appreciable heat evolution in the zone of condensation. Modern physics of gases and vapors gives the following explanation of the process. Gases and vapors exist in the rarefied state in soil materials: molecules move linearly without colliding, except with the pore walls, and gain or lose energy as they move along a temperature gradient. Having only reciprocating motion (3 degrees of freedom), molecules immediately lose two-thirds of their initial energy upon entering a porous medium (4, 5, 15, 18, 27, 28).

Water vapor ordinarily effuses toward lower temperature, hence its molecules gradually lose energy and velocity, and are eventually adsorbed on particles of earth, their water films, or even ground-water without substantial heat evolution (14, 22, 25). Thus, the transfer of gas or vapor molecules in soil materials proceeds without substantial energy consumption, according to the nature of non-isothermal counter effusion. This is verified by Table 7. (The soil was a southern chernozem, UONDC, Zaporozh region). Since the soil in the 50 to 100 cm. layer contained less than twice the hygroscopic moisture, water could move only in the vapor form. Movement toward lower temperatures prevailed in the soil material. Vapor sorption, or possibly condensation, in the 50 to

TABLE 7

Temperature and moisture dynamics of the soil after sprinkler irrigation of alfalfa (Average intensity, 0.43 mm./min. Water applied, 30 mm. Bulk density, 1.25 g./cm.^{3} Area shaded with an awning.)

Depth, cm.	Before irrigation		After irrigation			After 1 day			After 10 days		
	Moisture, %	Temperature, °C.	Moisture, %	Temperature, °C.	Moisture supply in layer, m³/ha.	Moisture, %	Temperature, °C.	Moisture supply in layer, m³/ha.	Moisture, %	Temperature, °C.	Moisture supply in layer, m³/ha.
0	1.76	21.5	28.12	19.5	175.8	25.30	23.4	158.1	7.05	23.5	44.1
0–5	—	—	29.31	—	183.2	28.40	—	177.5	23.26	—	145.4
5–10	10.6	23.1	26.55	21.3	165.9	27.71	21.4	173.2	26.43	21.8	165.7
10–15	—	—	24.66	—	134.1	25.33	—	158.3	24.83	—	155.2
15–20	14.8	23.1	15.42	22.0	94.4	17.72	20.6	110.8	22.84	21.6	142.7
20–25	—	—	14.67	—	91.7	16.42	—	82.1	21.09	—	131.8
25–30	14.6	23.5	13.62	23.2	85.1	14.76	22.2	92.3	14.08	19.0	88.0
30–35	—	—	13.75	—	85.9	14.57	—	91.1	13.94	—	87.1
35–40	13.2	—	14.37	22.8	89.8	14.13	—	88.3	13.70	—	85.6
40–45	—	—	14.63	—	91.4	14.28	—	89.3	13.95	—	87.2
45–50	13.5	22.0	13.93	22.0	87.1	12.02	23.5	75.1	13.38	19.6	83.6
50–60	14.1	—	14.38	—	89.9	13.22	—	78.1	15.55	—	97.2
60–70	13.9	—	13.35	—	83.4	13.60	—	85.0	16.12	—	100.8
70–80	12.9	—	13.55	21.6	84.7	14.05	—	87.8	17.40	—	108.8
80–90	12.2	—	12.85	—	80.3	13.92	—	87.0	16.77	—	104.8
90–100	12.8	21.0	15.19	21.0	94.9	14.59	20.0	91.2	16.11	18.0	100.3
Moisture content in 0–100 cm. depth.					1737.6			1725.2			1715.7

100 cm. layer was not accompanied by increased soil temperature.

Conclusions

1. Soil materials are a system of narrow interstices and pores; their size is equal to or less than the distance of mean free path of gas and vapor nolecules. Under these conditions gases and vapors are in a rarefied state and do not follow strictly the well-known hydrodynamic laws.

2. The laminar temperature distribution in soil naterial and the resulting stratification of gas nixtures attest to the absence of convective flow as a mechanism of gas or vapor transfer in soil naterials. This was confirmed by experiment.

3. The observations indicate molecular counter effusion of gases and vapors in soil materials, combined with their sorption on the solid and iquid phases.

4. In counter effusion, gas and vapor molecules ouch only the pore walls, acquiring the temperature of the contact point, and thus gaining or losng energy.

5. In moving along a temperature gradient, CO_2 gains energy, O_2 and water vapor lose it. As a result, the speed of counterflow of different gases and vapors is equal in every section of the soil naterial. But gases and vapors transfer selectively without destroying the gradient; one toward higher, another toward lower temperatures.

6. The process of counter effusion of gases in porous medium proceeds spontaneously, without visible energy requirement, and gases and vapors may move toward higher concentrations. Up to limiting concentrations, gases are sorbed without apparent heat evolution, since the sorption occurs at minimum kinetic energy of the molecule.

7. In soil materials, non-isothermal counter effusion (thermal effusion) and the sorption of gases and vapors predominate and are regulated by the temperature regime. In the upper plow layer, convective flow, diffusion and thermal diffusion of gases and vapors are also possible.

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VATER EROSION OF SOILS IN ESTONIAN SSR

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SOIL erosion in Estonia is not very common. It is more pronounced in the southeastern part of e republic on the uplands of Haanja and Otepää here the topography is hilly, dissected moraine. imilar topography is found on the uplands of andiwere and Sakala to a lesser degree. These laces occupy about one tenth (4000 square kilmeters) of the total area of Estonia.

Characteristics of the Areas Affected by Erosion

The uplands of Haanja and Otepää are basially of tectonic origin, covered with thick moaine deposits. Composition of the moraine is liversified: the material may be of a glacial oriin, of alluvial-glacial or of a lacustrine-glacial ature. The thickness of the moraine of the Haanja Upland is over one hundred meters in laces; Otepää Upland is about 30 to 40 meters. The Pandiwere Upland in Northern Estonia is lso of a tectonic origin, but the thickness of the lacial deposits here varies from two to five meers.

The hilly moraine relief is typical of the Haanja and Otepää Uplands. The Pandiwere Upand has the aspect of a plain with occasional low lrumlin ridges. Areas south of the Upland are ypical drumlin fields. The length of the drumlins enerally varies from 2 to 10 kilometers; the vidth, from 0.2 to 2 kilometers; the height, up o 60 meters.

In degree of dissection of the relief and intenity of erosion, the territory of the republic may e divided into several groups. (See Fig. 1.) The irst group comprises the central parts of the Dtepää and Haanja Uplands. The relief is much lissected, hilly, characterized by dome-like hills vith closed (—no outlet) depressions in between. These hills have relative elevations of 25 to 50 meters, occasionally 70 meters. Cultivated areas re usually on the slopes, with a gradient of 10 o 20 degrees, in places 30 degrees. For a 100 ectare area, the number of elevated forms of he terrain varies generally between 50 to 75. To his group (1) belongs 1.8 percent of the total rea of the republic.

Border parts of the Otepää and Haanja Upands, some areas on the Pandiwere Upland, and in few other places belong to the second group. The topography of the land in this group is not cut as much as land in the first group. Drumlins and dome-like hills with gentle slopes are typical forms of terrain. Relative elevations vary here from 10 to 25 meters; steepness of the slopes is 5 to 15 degrees. To this group (2) belong about 3.3 percent of the total area of Estonia.

Places with mildly dissected, rolling, hilly topography belong to the third group. Relative heights are from 5 to 10 meters; steepness of the slopes is 3 to 6 degrees. About 4.4 percent of the total area of the republic belongs to this group.

In the fourth group are included areas of rolling plains, dissected by ancient valleys. Generally, steepness of the slopes in this area varies from 0 to 3 degrees; it reaches 30 degrees only on the valley slopes. The remaining parts of the republic are characterized by plain or slightly undulating topography. Steepness of slopes varies here from 0 to 3 degrees, occasionally reaching 15 degrees in moraine ridges or in eskers.

At present there is no erosion of the slopes covered with original vegetation (i.e. forests) except in rare cases. Erosion is also not observed on the slopes used for unimproved pastures or hayfields. We therefore have in mind contemporary, man-made erosion of cultivated land in our discussion of soil erosion in Estonia.

The percentage of cultivated land of the Otepää and Haanja Uplands is relatively high: in the central part (the first group) 57.4 percent, and in the border part (the second group) 64.8 percent of the total area of agricultural land of Estonia (average of the four regions).

The nature of the cultivated land is related to the degree of soil erosion. Grain and legume crops are not too efficient in preventing erosion of the soil. These comprise 56.5 to 57.5 percent of the cultivated land. Forage crops cover about 20 percent of the area (average of the four regions for 1954). Fallowed fields are also found in the regions under consideration.

The method of cultivation is an essential factor influencing soil erosion. Use of tractors has become prominent during recent years. The tractors commonly used are of DT-54 series, NATI;

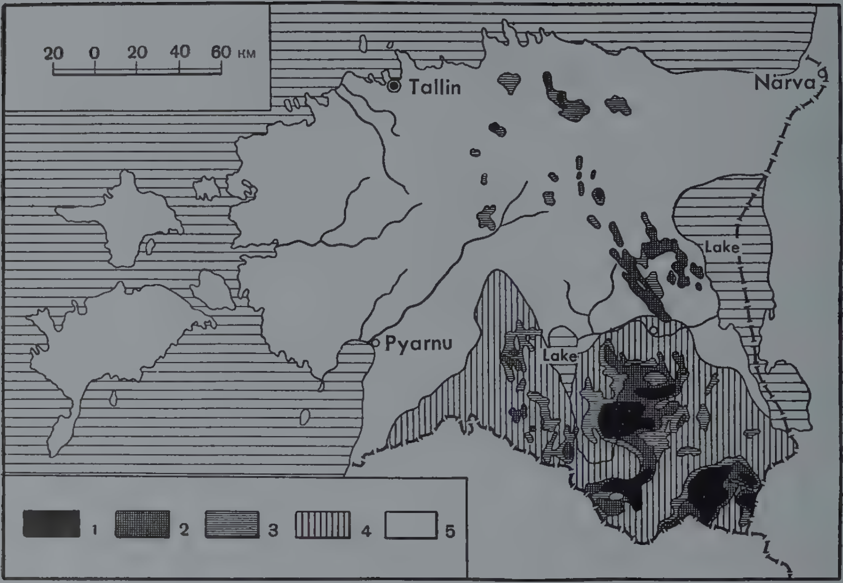

FIG. 1.—Map showing extent of water erosion of soils in Estonia (compiled by R. Kask). 1—Area of much dissected, rolling topography; severe erosion (Group one). 2—Area of moderately dissected topography; moderate erosion. (Group two); in places in presence of drumlins, moderate erosion. 3—Hilly or undulating, slightly dissected area; slight erosion. 4—Area of undulating plains, dissected by ancient river valleys; erosion only localized. 5—Level areas or slightly undulating plains; erosion either localized or totally absent.

these are powerful machines, making wide strips but with limited maneuverability, especially in a hilly country. Accordingly, the quality of the cultivation has decreased and in recent years soil erosion has been considerably intensified in various places.

SHEET EROSION IN THE REPUBLIC. Sheet erosion—soil erosion—is very common on the Otepää and Haanja Uplands, where almost all fields are located on the slopes. Intensity of soil erosion varies within large limits. In general, when over 50 cubic meters of soil are eroded from one hectare in one year, then the erosion is considered to be severe. This type of erosion is a rill type. Soils of the eroded slopes may be divided into three groups: 1) eroded, 2) partly eroded and partly alluvial and 3) alluvial. Occurrence of these types depends on the slope (Table 1).

Intensity of erosion on similar slopes may vary depending on soil conditions and methods of cultivation, although the degree of erosion is generally related to steepness of the slope. (Table 2).

TABLE 1

Distribution of eroded soils on different type slopes

Slope type	Slope length %		
	eroded soils	eroded-alluvial soils	alluvial soils
Convex	>80		<20
Concave	25–40	5–10	60–70
Concave-Convex	50–70	5–15	25–35
Straight (5 to 15°)	10–20	50–70	15–25

TABLE 2

Relation of erosion to slope

Degree of erosion	Slope, degrees
Not eroded	0 to 3
Slightly eroded	3 to 7
Medium "	5 to 12
Severely "	12 to 25
Very severely "	>20

Most eroded and alluvial soils are found in the central Otepää and Haanja Uplands. On the periphery, because dissection of the relief is not so deep and not so intensive, there are less of soils of this nature.

Data showing distribution of erodible soils are given in Table 3. As seen from this table, almost all cultivated land is susceptible to erosion in the central parts of the Uplands (Group One). On the periphery (Group Two) of the Uplands only about one-half of the cultivated land is subject to erosion (except very slightly eroded soils on the slopes—lower than 3 degree).

Soil grouped according to degree of erosion and the deposition of (alluvial) soils are given in Table 4. Predominant among the eroded soils are sod-podzolized (meadow-podzolized type), mostly slightly- and medium eroded; severely and very severely eroded soils predominate among the sod-carbonated soils. (Table 5). It follows that the sod-carbonate soils are more susceptible to erosion. An important factor here is the carbonate content of the underlying parent material; it is more pronounced on tops and on steeper slopes of the hills.

TABLE 3

Distribution of erodible soils in Otepää and Haanja Uplands

Area group	Cooperative farm name (Kolkhoz)	% of total Kolkhoz land		Area of Mineral soils,[a] %		Eroded and sod-alluvial soils % of total area of cultivated land
		Eroded[c]	Sod-alluvial	Eroded	Sod-alluvial[b]	
I	Munamiagi, Wyrussa region	34.06	17.35	47.8	21.9	100
I	Kingissepp, Wyrussa region	31.7	15.8	44.2	21.5	89
I	Arula, Otepää region	38.2	17.7	60.1	28.1	100
II	Kiundia, Wastselna County	13.5	6.4	20.8	9.8	51

[a] Mineral soils are: podzolized, sod-carbonate and sod-alluvial.

[b] Sod-alluvial soils (saturated and unsaturated) are formed on the sod-podzolized and sod-carbonate soils on the lower parts of the slopes.

[c] Genetically of sod-podzolized and sod-carbonate types.

TABLE 4

Degree of eroded and alluvial soils in Group I areas

Name of Kolkhoz	Eroded soils, %				Alluvial soils, %		
	Slightly	Medium	Severely	Very severely	Sod-alluvial	Sod-alluvial, Gley-like	Sod-alluvial, Gley
	Eroded						
Kingissepp, Wyrussa region	41	37	22		85	7	8
Arula, Otepää Country (Kliuch area)	37	33	26	4	75	16	9

TABLE 5

Eroded soil distribution of Haanja Upland, according to genetic group (Kingissepp Kolkhoz, Wyrussa region

Degree of erosion	Sod-Podzolized (78% of all eroded soils)	Sod-carbonate (22% of all eroded soils)
Slightly eroded	46	24
Medium eroded	38	31
Severely and very severely eroded	16	45

AGRONOMICAL CHARACTERISTICS OF ERODED AND SOD-ALLUVIAL SOILS[1]

Changes in humus and nitrogen contents in eroded soils. Humus content of non-eroded arable soils of the Otepää and Haanja Uplands and adjacent areas average from 75 to 100 metric tons per hectare. The plowed layer of 20 cm. contains about 60 metric tons of humus per hectare (2 percent). Humus content of eroded soils decreases with the increase of erosion intensity. In the plowed layer of slightly eroded soils, humus content is generally higher than 1.8 percent; in medium-eroded soils, 1.3 to 1.8 percent; in severely eroded, 1.0 to 1.3 percent and in very severely eroded, from 0.4 to 1.0 percent.

Depth of the plowed layer varies generally from 15 to 20 cm. (no matter how much soil had been eroded). In the horizon below, humus content is sharply reduced. Total humus content in eroded soils varies as follows: slightly eroded, more than 75 metric tons per hectare; medium eroded, 50 to 75 metric tons; severely eroded, 25 to 50 metric tons and very severely eroded, less than 25 metric tons. In the 20 cm. surface layer, the respective quantities are: slightly eroded, more than 45; medium eroded, 30 to 45, severely eroded, 15 to 30; and very severely eroded, less than 15 metric tons per hectare. Humus content of the plowed layer in the sod–alluvial soils is generally higher than in the eroded soils, and it is often even higher than in non–eroded soils. When erosion is slight, the alluvial material usually comes from A horizon. When erosion is more severe, the alluvium comes from horizons A_2 and B and the humus content in the sod-alluvial soils is smaller than in the non-eroded soils, but larger than in the eroded soils. When the (alluvial) material comes from horizon C, (as in the case of rill-type erosion) humus content in the sod-alluvial soils is almost always smaller than in eroded soils.

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[1] Agrochemical generalizations are made on the basis of analyses of samples from 75 soils profiles. Only typical examples are given in this article.

Some data pertinent to humus content in eroded and sod-alluvial soils are given in Table 6. Thickness of the humus horizon of sod-alluvial soils may reach 1.5 meters. The total humus content in the whole profile of the sod soils containing a great deal of alluvium is from 5 to 10 times higher than in eroded soils.

The results of the analysis showed that the plowed-up (surface) layer of eroded soils contained 0.04 to 0.12% total nitrogen content; in the surface layer of the sod-alluvial soils nitrogen content is generally higher, but in the case of rill-erosion it is lower. Total nitrogen content in the sod-alluvial soils is considerably higher than in the eroded soils. Ratio of carbon to nitrogen in eroded soils is usually less than 10. With increas of erosion C/N ratio decreases. In the sod-alluvia soils the C/N ratio is higher than in the erode soils, but in some cases (rill erosion) the rati might be reversed. The C/N ratio in the lowe strata of the alluvial material is higher than i the upper layers.

Changes in Phosphorous Content (*P_2O_5*) *an* *Potassium* (*K_2O*) *in eroded Soils.* Our analyse showed that eroded soils are richer in solubl phosphorous than sod-alluvial soils and severel eroded soils are richer than the slightly eroded Eroded soils also proved to be richer in phosphorous soluble in 20% HCl (Table 6).

Content of soluble phosphorous in eroded soils increases with depth, but decreases in the lower layers of the alluvium of the sod-alluvial soils. Ratio of phosphorous soluble in 20% HCl to the soluble phosphorous in 0.2 N HCl in eroded soils is lower than 15. This ratio decreases with increased erosion while in the sod-alluvial soils it is higher than 15, and in the lower layers of the alluvium it increases.

Regarding soluble potassium, most of it is found in the plowed (surface) layer. In deeper horizons potassium content rapidly decreases. Accordingly, with removal of the surface layer, content of soluble potassium decreases. Amount of soluble potassium in eroded soils is generally

TABLE 6

Chemical characteristics of eroded and of sod-alluvial soils of Kolkhoz Munamiagi (*Wyrussa County*[a])

Soil	Horizon	Depth, cm.	Texture	Humus, %	Total Nitrogen, %	C/N Ratio	P_2O_5 soluble in 0.2 N HCl Mgms in 100 gm. soil	P_2O_5 soluble in 20% HCl, %	Ratio of P_2O_5 soluble in 20% HCl to P_2O_5 soluble in 0.2 N HCl	K_2O soluble in 0.2 N HCl Mgms in 100 gm. soil	K_2O soluble in 20% HCl, %	Ratio of K_2O soluble in 20% HCl to K_2O soluble in 0.2 N
Sod-carbonate, severely eroded	Ap	0–15	Sandy loam	1.13	0.091	7.2	24.0	0.220	9.2	7.5	0.351	47
	BC	15–35	"	0.28	0.027	6.0	28.0	0.227	8.1	2.0	0.301	151
	C	35–56	"	—	—	—	35.0	0.229	6.5	1.4	0.237	169
Sod very thick alluvium	AN	0–5	Sand	0.37	0.028	7.5	17.3	0.124	7.2	2.0	0.096	48
	A_1N	5–20	Sandy loam	1.34	0.089	8.8	13.3	0.236	17.7	5.0	0.103	21
		20–40	"	0.99	0.068	8.4	8.5	0.111	13.1	2.4	0.118	49
		40–60	"	0.91	0.060	8.8	4.5	0.126	28.0	—	—	—
		60–80	"	0.91	0.048	11.5	3.3	0.102	31.0	0.6	0.050	83
	A_1/A_1N	80–100	"	1.06	0.052	11.8	3.2	0.096	30.0	1.2	0.078	65
	A_2B	105–125	"	0.71	0.037	11.0	4.1	0.085	21.0	2.8	0.083	30
	B	125–145	Clay loam	0.24	0.025	5.8	9.3	0.131	14.1	2.4	0.260	189
	C	160–180	"	—	—	—	29.0	0.216	7.4	8.1	0.213	69

[a] Humus determined by Tyurin's method; Nitrogen by Kjeldahl; soluble phosphorous in 0.2 N HCl; soluble potassium by Peive's method.

ess than 10 mg. per 100 gm. of soil. It decreases vith increase of degree of erosion. Content of oluble potassium in the sod-alluvial soils is maller than in the eroded soils. In the lower ayers of an alluvial horizon of the sod-alluvial oils, percentage of potassium decreases. Content of potassium, soluble in 20% HCl in the eroded oils is higher than in the sod-alluvial soils. Ratio of potassium soluble in 20% HCl to the soluble potassium in 0.2 N HCl is higher in the eroded oils than in the sod-alluvial soils. In the lower horizons of eroded soils and in the lower layers of he alluvial horizon of the sod-alluvial soils, this atio increases.

Changes in Physico-Chemical soil characteristics n connection with erosion. When surface horizons re eroded, physico-chemical characteristics of roded soils change and begin to approach those of the lower horizons and of the parent material. Since the lime content of the parent material in hose parts of Estonia where erosion is widespread increases with depth, the lower horizons of the eroded soils are generally richer in lime han non-eroded soils. (Table 7.) With increase of erosion, (soil) acidity decreases, while degree of saturation of the soil and content of adsorbed cations become higher. It is seen especially clearly in the case of eroded soils, that had developed on carbonate moraines. Very severely eroded soils on carbonate moraines generally have alkaline reaction, in spite of the fact that the original soils (developed on the moraines) had been of a sod-podzolized group.

Physico-chemical characteristics of sod-alluvial and of eroded soils are different. The pH value of the alluvial soils is lower (sometimes to an extent of two units); the hydrolytic acidity is higher (up to 4 mg.–equiv. of 100 gm. of the soil); content of adsorbed cations is smaller than in the eroded soils of the same slopes. Also dissimilar are the physico-chemical characteristics of the upper and the lower layers of the alluvial horizon of the sod-alluvial soils; the pH value (in KCl extract) of the upper layers (of the alluvial horizon) is sometimes two units higher than in the lower layers; hydrolytic acidity is lower, the difference sometimes being as high as 2 to 3 mg.–equiv. of 100 gm. of soil.

Content of adsorbed cations in the upper layers of the alluvial horizon is higher, sometimes as much higher as 2 to 10 mg.–equiv. of 100 gm. of the soil, and the degree of cation saturation of

TABLE 7

Physico-Chemical characteristics of eroded and sod-alluvial soils on convex-concave slopes in Kolkhoz Munamiagi, Wyrussa County

Soil	Horizon	Depth, cm.	Texture	pH in KCl extract	Hydrolytic acidity Mg.-Equiv. of 100 gm. soil	Adsorbed cation Mg.-Equiv. of 100 gm. soil[a]	Degree of saturation, %
Sod-podzolized, slightly eroded	Ap	0–20	Clay	5.2	2.89	14.4	83
	B	20–40	"	6.6	0.70	—	—
	C	40–60	Clay loam	6.8	0.70	—	—
Sod soil with slight alluvium	Ap	0–20	"	5.1	4.99	6.9	58
	A_1/A_1N	20–40	"	4.5	4.99	4.8	49
	A_2B	50–65	"	4.5	2.54	2.3	48
	A_2	65–90	"	4.6	1.75	3.7	68
	V	90–100	"	4.5	2.19	7.7	78
Very severely eroded, carbonate	Ap	0–20	"	7.1	0.53	—	—
	C	20–40	"	7.3	0.44	—	—
Sod soil with very thick alluvium	A_1N	0–20	Sandy loam	7.0	0.61	15.0	96
		20–40	"	6.9	0.70	7.7	92
		40–60	"	6.7	0.96	6.3	87
		65–85	"	6.6	1.23	6.9	85
		85–100	"	6.5	1.14	4.3	79
	A_1/A_1N	100–110	"	6.5	1.58	8.0	84

[a] Determined according to Kappen.

the soil is higher, in some cases up to 40% in comparison with the lower layers. The difference of physico-chemical data between upper and lower layers of the alluvial horizon increases with the amount of the alluvium.

Agricultural Crop Yields on Eroded and Sod-alluvial Soils. Yield of grain crops on eroded soils in Estonian SSR is generally several times smaller than on the sod-alluvial soils. There is not that much difference in the case of perennial grasses grown on eroded soils as compared with sod-alluvial soils, nevertheless the yield decreases with erosion increase. The difference in crop yield from eroded soils as compared with the sod-alluvial soil increases with a low management level and *vice versa.*

Not only less grain crop is produced on eroded soils, but also its quality is poorer; weight of 1000 seeds of grain crops is smaller on the eroded soils than on the sod-alluvial soils. (Table 8). Low yield of agricultural crops on eroded soils caused chiefly by low soil fertility. Moreove yield is lowered because of mechanical damag done to the plants, washing out their roots, et Difficulty of soil cultivation and of a proper car of the plants on the slopes also contributes to th low yield.

TABLE 8

Agricultural crop yield of an eroded and sod-alluvial soils in 1952

Farms and Regions	Soil	Crop	Yield of grain cntr./ha.	Yield of straw or grass cntr./ha.	Wt. of 1000 seeds, gm.
Sovkhoz Nyo Elwasa region	Sod-Podzolized, slightly eroded	Barley	21.4	18.5	41.7
	Sod-Podzolized medium eroded		20.3	19.2	39.8
	Sod-medium alluvial		34.6	37.9	42.7
Kolkhoz Kundia Wastselinas region	Sod-Carbonate severely eroded	Wheat	3.4	4.0	—
	Sod-slight alluvial		28.3	45.4	—
Kolkhoz Waba-Kodu Elwasa region	Sod-podzolized slightly eroded	Oats	16.2	16.2	30.7
	Extremely severely eroded carbonate		4.6	4.9	29.3
	Sod-slight alluvial		24.6	20.6	32.9
Kolkhoz Stalin Otepää region	Sod-carbonate severely eroded	Perennial grasses	—	30.4	—
	Very severely eroded, carbonate		—	18.2	—
	Sod-considerable alluvium		—	50.5	—

Gully Erosion. Gullies are chiefly found on th hilly moraine terrain of the Otepää and Haanj Uplands. In these localities, there are in averag two gullies for each square kilometer. Distribution of gullies on slopes of the river valleys (Grou four), is not uniform. On the slopes of the Kawilda River valley there were detected along tw (linear) kilometers—eight gullies: the first kilometer had 6 gullies and the second had two.

The most common type of gullies in the republic are small gullies. Reaching 0.5 to 2.0 meters in depth, they generally expand into gently sloping narrow depressions, which gradually become covered with heavy sod. Such gullies are typical in places where watersheds are of a limited size. Where watersheds are large, there may be found gullies that are continually growing in size. Slopes of ancient valleys are very favorable for development of such gullies. In such places occur the biggest gullies and ravines of the republic.

More common in the republic are riverbank gullies. This type of gully is typical to the hilly moraine country; they also occur on the slopes of river valleys. But more typical to the river valleys are secondary, valley gullies; less frequent are the primary, up-country gullies. Generally, Estonian gullies are rather small; rarely they are deeper than 20 m. and longer than 500 m.; generally they are 5 to 10 m. deep and 200 to 300 m. long. The most frequent are enlarged rills, whose depth varies from 0.5 to 2 m.

One of the important factors causing magnitude and intensity of erosion is steepness of the slopes which reaches 30° in some cultivated areas; the other important factor is a considerable dissection of the land. Factors favorable to the erosion control are: relatively short slopes, relative stability and resistance of the parent material to sheet and gully types of erosion, relatively small intensity of precipitation and slow melting of snow. It should be noted that in cultivation of land of Estonia not enough attention is being paid to soil erosion.

The most widespread and important in Estonia is sheet erosion. About 60,000 hectares of all arable land—7% of the total arable land of Estonia. Average agricultural crops yields of the farms located on the Otepää and Haanja Uplands are the lowest in Estonia. For instance, in 1953, average yield of grain crops per hectare in the Kingissepp Kolkhoz of Wyrussa region was 1.8 times smaller and barley yield was 2.2 times smaller than the yield of Vil'yams collective farm (of the same region) where the land is flat.

Erosion control on the Otepää and Haanja Uplands is not only of a local but also of a general importance to the republic. Eight out of 38 regions of Estonia are seriously affected by erosion.

Suggested measures of erosion control in the Otepää and Haanja Uplands comprise merely one component of the whole organization of agriculture in the places with hilly relief of the country. As a result of studies in the foregoing regions, some practical suggestions have been made; these are important for further development of agriculture. Such are: establishment of pastures on the present severely eroded cultivated land, increase to 30–35% area of forage crops (clover, timothy), introduction of alfalfa etc. and corresponding reduction of grain crops.

Control of gullies in Estonia cannot be considered as a separate problem. As soon as sheet erosion is under control, gullies will not originate.

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SECOND PLENUM OF THE COMMITTEE ON THE NOMENCLATURE, SYSTEMATICS, AND CLASSIFICATION OF SOILS O THE ACADEMY OF SCIENCES, USSR

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A SCHEDULE of the activities of the Second Plenum of the Joint Committee on the Nomenclature, Systematics, and Classification of Soils was outlined at previous sessions in February 1957 (Pochvovedeniye No. 8, 1957). The Second Plenum was held from February 5–8, 1958 at the V. V. Dokuchayev Soil Institute, Academy of Sciences, USSR. The following problems were discussed:

1. The principles of the systematics of soils of the steppe zone of the USSR.
2. The organization of work on the diagnostics of soils and on the preparation of an explanatory dictionary on soil terminology.
3. Continuation of work, and resolution of problems discussed at the Committee's First Plenum.

SYSTEMATICS OF THE STEPPE SOILS OF THE USSR

The principles of the systematics of soils in the steppe zone of the USSR were discussed on the basis of data prepared for the Plenum by YE. N. Ivanova, N. N. Rozov and other committee members and contained in the report "Experiment in the systematics of the steppe soils of the USSR," including an account of a report by A. A. Rode on the results of studying these data at the sessions of the working group of the Committee.

The report recommended that soils of the steppe zone be systematically divided (separated) into six main groups—the chernozems, chestnut, meadow-chernozem, meadow-chestnut, meadow, and meadow-bog soils. The systematics of salinized soils in the steppe zone (the solonchak, solonetz, and solodi) were not studied inasmuch as the question of separating these soils required only one solution for all of the soil zones. Because of the vast amount of material involved a proposal was made to divide the report and discussion into two sessions.

The first two sessions were devoted to the study of the systematics of chernozems and chestnut soils.

In accordance with the definition for the taxonomic units in soil systematics accepted a the sessions of the First Plenum of the Committee the report contained a proposal to divide th chernozem soil group and the chestnut soil grou into 11 and 7 subgroups, respectively, keepin in mind the subgroup transitions of these soils t corresponding subgroups of brown forest, cinnamon-brown and grey cinnamon-brown soils no only in a north-south direction (by subzones) bu also in an east-west direction (by facies). To illustrate this more clearly, a working classification of the subgroups by facies features was proposed.

The following three facies of subgroups have been distinguished within the chernozem group the Central facies with subgroup of podzolic, leached, typical ordinary southern chernozems; the Western facies (south-European or Black Sea region) with subgroups of "deeply-mycelium-carbonate", "mycelium-carbonate", "highly mycelium carbonate" and "mycelium-carbonate chestnut" chernozems; and the Eastern facies (east Asiatic) with subgroups of "ordinary washed" and "southern-washed" chernozems.

Three facies of subgroups have been distinguished within the chestnut soil group: the Predkavkazskaya facies with a subgroup of mycelium-carbonate dark-chestnut soils; the European-Kazakhstanskaya facies with subgroups o dark-chestnut, chestnut and light-chestnut soils; and the Central-Asiatic facies with subgroups o "washed dark-chestnut", "washed chestnut" and "washed light-chestnut" soils.[1]

The generic subdivisions are indicated and arise from the definition accepted for the kinds of soil. The genera are distinguished within the corresponding subgroups of chernozems as residual-podzolic, residual-leached, noncarbonate, residual-carbonate, residual solonetzic and solonetzic chernozems. Chernozems, which directly correspond to the subgroup, and chernozems on coarse-textured parent materials have also been separated into special genera. In similar manner the chestnut soils were separated into genera.

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[1] The provisional working designations are enclosed in quotation marks. "Mycelium-carbonate" is understood to be steppe soil containing a high migration capacity of carbonates. By "washed" is meant steppe soil deprived of readily soluble salts.

Chernozems were separated by species following a decision accepted by the All-Union Conference of Soil Scientists in 1950 (see the legend of the State Soil Map, Soil Science 1950, No. 4).

A general picture of the humus, carbonate and salt profiles of the principal species of chernozems was presented on special diagrams for the following provinces: Pridunayskaya, Zapadno-Predkavkazskaya, Tsentral'no-Predkavkazskaya, Ukrainskaya, Srednerusskaya, Priural'skaya, Zapadno-Sibirskaya, Predaltayskaya, Tsentral'no-Sibirskaya, Zabaykal'skaya, and Vostochno-Aziatskaya. On the whole, the working subcommittee approved the proposals which had been advanced. Comments by various members of the working group (for the most part repeated at the sessions of the Plenum) are given below.

The president of the Committee, I. V. Tyurin, proposed that the discussion be devoted to the questions:

1. Have the group, subgroups, genera and species of soils been properly divided?
2. Has the introduction into the taxonomic unit system of the "facies" and "provinces" been advisable?

In the discussions which followed K. P. Gorshenin and YE. V. Rubilin supported the separation of chernozems into two independent groups—"the forested-steppe chernozem" and the "steppe chernozem". An even more complicated scheme was proposed by N. A. Nogina and YU. A. Liverovskiy who considered that four or five independent genetic groups of soils can be distinguished among the chernozems which would correspond more accurately to the accepted definition for the soil group than the chernozems as a whole. Furthermore, Gorshenin, in accordance with earlier expressed views, proposed in a letter that the strongly solonetzic chernozem and the strongly-solonetzic chestnut soils should be separated from their corresponding groups and should be related along with the steppe solonetzes to a group of "steppe solonetz soil".

A. A. Zavalishin, F. YA. Gavrilyuk, S. V. Zonn, P. G. Aderikhin, G. N. Sambur, M. N. Pershina, U. U. Uspanov, B. A. Kalachev, D. M. Storozhenko, A. N. Rozanov, YE. N. Ivanova and others favored the idea of preserving a single group of chernozem and did not particularly object to the definition of soil group accepted by the Committee. Furthermore, U. U. Uspanov proposed including among the chernozem and chestnut soils the correspondingly meadow-chernozem and meadow-chestnut soils, which, however, did bring forth opposition from several members of the Committee.

After summing up the discussion results, I. V. Tyurin directed his attention to the fact that most Committee members were in favor of preserving the chernozem group within its former limits and placed particular importance on the role of the biological factor in resolving this problem. Apparently, we cannot always consider the "five criteria" in the definition of the soil group, which we accepted, as fully equivalent. Therefore, within the broad chernozem group we must, first of all, separate the great zonal groups—the forested steppe and steppe groups, and then the facies.

The facies of subgroups were approved as working genetic units by A. A. Zavalishin, S. V. Zonn, M. N. Pershina, A. N. Rozanov, and V. R. Volobuyev. K. P. Gorshenin, B. A. Kalachev, G. N. Sambur and others objected to including these groups into the basic system of taxonomic units.

Many members proposed distinguishing besides the groups designated in the report, a West Siberian facies of chernozem subgroups, indicating their original (peculiar) morphological (linguistics) "relations" and other features (N. A. Bazilevich, YE. A. Afanas'yeva, YU. A. Liverovskiy, A. N. Rozanov). M. N. Pershina recommended separating the Kazakhstanskiye chestnut soils from the east European chestnut soils on the basis of special subgroups included in the various facies.

S. V. Zonn and YE. V. Rubilin devoted their attention to the erroneous concept of incorporating the Pridunayskiye and Predkavkazskiye chernozems within one subgroup. These chernozems differ basically by thickness; in addition, the Pridunayskiye chernozems are mycelium-carbonate for a very great depth while in the Predkavkazskiye chernozems a white fleck occurs below the pseudo-mycelium layer. G. N. Sambur pointed out the need of separating the subgroups of regarded chernozem for the Ukraine.

With respect to the nomenclature of the chernozem subgroups, critical opinions were expressed on the terms "typical" (P. G. Aderikhin, S. V.

Zonn) "mycelium" (K. P. Gorshenin, F. YA. Gavrilyuk) "podzolic" (V. R. Volobuyev) and "washed" (B. A. Kalachev) but no substitutes for these terms were advanced. K. P. Gorshenin expressed doubt as to the existence of typical chernozems as a subgroup, admitting the possibility of relating them to the ordinary (or partly to the leached) chernozems as "very deep" and "rich" types.

Objection was not raised to the proposed generic subdivisions of chernozems and chestnut soils.

The following remarks were made concerning the subdivisions of chernozems and chestnut soils into species and division by provinces: K. P. Gorshenin proposed renaming the Tsentral'no-Sibirskaya province of chernozems as the Prisayandskaya province and separating the Severo-Kazakhstanskaya province of chernozems; B. V. Nadezhdin proposed dividing the Priangarskaya province of chernozems.

K. P. Gorshenin, A. A. Zavalishin, U. U. Uspanov and others expressed their views on including the provincial subdivisions in the basic system of taxonomic units. Problems remained unsolved on how the provincial association of soils was expressed in their nomenclature and on the use of geographic names. In the Committee's opinion these problems should be considered for all soil groups at one and the same time.

The third session was devoted to a study of the systematics of meadow-chernozem, meadow-chestnut, meadow and meadow-bog soils.

In their report YE. N. Ivanova and N. N. Rozov proposed the following subgroups of these soils: the meadow-like chernozem and meadow-chernozem as meadow-chernozem soils; the meadow-like-chestnut and meadow-chestnut for the meadow-chestnut soils; the "intermittently wet" meadow (deeply gleyed), "constantly wet" (highly gleyed) meadow for the meadow soils. The meadow-bog soils do not have subgroup divisions (i.e., are not related to a single subgroup).

In all of the subgroups mentioned the genera of leached "typical" (normal for the subgroup) carbonate, leached, solonetzic and solonchakic soils were separated. The podzolic and residual-solonetzic solodi soils were separated from the meadow-chernozem soils and the marl soils were separated from the meadow and meadow-bog soils.

In a report made in the name of the working subcommittee, A. A. Rode showed that the proposed soil groups and their generic subdivision did not meet with serious opposition. A series o supplementary proposals was introduced regarding the subgroup divisions of meadow-steppe soils These divisions were set up to express within th subgroup division not only the degree but also th nature of moisture and possibly several subzona and facies differences.

In the ensuing discussions on the number o groups, B. A. Kalachev proposed combining th meadow-chernozem and meadow-chestnut soil into a single group of meadow-steppe soil; K. P Gorshenin deemed it more accurate to relat the solonetz meadow-chernozem and solonetz meadow-chestnut along with the meadow solonetz to a type of "meadow-solonetz" soils; while U. U. Uspanov proposed incorporating, as already pointed out, the meadow-steppe soils with the chernozem and chestnut soils. These proposals were not supported in subsequent discussions.

Several discussions were devoted to the problem of dividing the meadow-chernozem and meadow-chestnut soils into subgroups. A. A. Rode and YE. N. Afanas'yeva, B. A. Kalachev, V. V. Yegorov, and N. I. Bazilevich were in favor of dividing the surface moisture and ground moisture soils at the subgroup level. Furthermore, A. A. Rode proposed considering still a third case, i.e., when the soils are formed on two-member parent materials, a layer of suspended capillary moisture is created in these materials. N. I. Bazilevich also considered it possible to express several great zonal and facies differences when separating subgroups. As far as terminology was concerned, A. A. Rode and V. V. Yegorov were in favor of defining more precisely the concept of meadowness in soils, which presupposes not only a more intensive accumulation of humus but the compulsory characteristics of recent hydromorphism, with a capillary rise of water.

Summing the results of the discussion on the systematics of the steppe soils of the USSR, I. V. Tyurin noted the absence of agreement among the Committee members on several classification questions, because of a lack of sufficient factual data, mostly on the eastern (and, in part, on the western) regions of the steppe zone.

The Plenum considered it necessary to submit the scheme proposed for the systematics of steppe soils and the subjects discussed to a large group of soil scientists.

The Plenum suggested that the working subcommittee and authors bring the discussion of the scheme to an end with the remarks already made (especially with respect to the subgroup divisions of meadow-chernozem and meadow-chestnut soils) and to present this scheme at the next Plenum of the Committee in order to arrive at final decisions.

ORGANIZATION OF WORK ON QUESTIONS OF NOMENCLATURE AND DIAGNOSTICS OF SOILS

As I. V. Tyurin pointed out at the first session, "The unification of nomenclature, systematics and methods of soil diagnostics" (Pochvovedeniye No. 8, 1957) are the principal problems of the Joint Committee. Research in soil systematics is presently being carried on by the Committee.

Soil nomenclature requires 1) the development of the general principles of nomenclature, 2) a precise definition of the basic terms and concepts involved, and 3) the reduction of local soil names to a single nomenclature together with a system of synonymics.

Soil diagnostics require 1) the development of the principles of diagnostics, 2) the establishment of basic diagnostic indicators and methods for determining them and 3) the collection of factual data for soil diagnostics.

A. A. Rode presented the Committee's program and preliminary plan of work. He pointed out 1) the necessity that Committee members participate in preparing a dictionary of soil terms which had been undertaken by the All-Union Society of Soil Scientists, 2) the need for unifying soil analysis methods and methods for observing their relations in order to order to properly establish the diagnostic indicators, 3) the desire to set up systematic soil collections and card indices of analyses, and 4) the need to develop a more thorough system for designating soil horizons. The basic ideas of A. A. Rode's report have been published in Pochvovedeniye (No. 9, 1957).

Eleven persons entered into a discussion of the report. I. V. Tyurin emphasized the fact that a dictionary of soil terms would have great international significance, in which connection it would immediately be necessary to establish the diagnostic indicators for the main groups and subgroups of soils. K. P. Gorshenin, A. A. Zavalishin, and V. R. Volobuyev introduced the proposal to establish a monograph on basic soil groups. A. A. Zavalishin, S. N. Taychinov, and YE. N. Ivanova referred to the need for establishing card indices for soil analyses; F. YA. Gavrilyuk and G. N. Sambur proposed including in this card index indicators of the agricultural value of soils according to the data of Gossortoset'.

S. V. Zonn, P. G. Aderikhin, and YE. N. Ivanova were in favor of defining more precisely the existing A-B-C system in the nomenclature of soil horizons; G. N. Sambur pointed out the advantages of the Sokolovskiy-Vilenskiy system.

V. G. Zol'nikov referred to the need of perfecting the methods for studying soils and, in particular, proposed using the isotope method and pollen analysis for determining the absolute age of soils. Several members were in favor of preparing a color atlas of USSR soils and of extensively applying color photography to soil science.

In his concluding remarks A. A. Rode dwelt on local organization problems in soil diagnostics which involved collecting material from specific soil profiles and summing up these data from lower systematic units according to the nomenclature approved by the Committee. The data of the Hydrometeorological Service could be used for the characteristics of thermal relations.

The Plenum resolved to set up special groups to deal with questions of soil nomenclature and diagnostics as part of the working subcommittee which were to organize work at the center and locally. The Plenum requested A. A. Rode to head the work of these groups.

Decisions on Data of the First Plenum of the Committee:

The Plenum again examined the scheme for determining the taxonomic units in soil systematics worked out at the last session of the Committee and published in Pochvovedeniye (No. 8, 1957); the Plenum discussed the critical comments on the soil group definition expressed by V. G. Zol'nikov and A. S. Atanelishvili and resolved, according to the proposal of I. V. Tyurin, V. A. Kovda, YE. N. Ivanova, K. P. Gorshenin and others, to introduce several changes into the former wording of the definitions and to approve the text in the following form. A great soil group is developed under biological, climatic and hydrologic conditions combined under a single group and characterized by a clear manifestation of the basic process of soil formation through a possible combination with the other processes.

Characteristics of the Soil Group are Determined:

1. By single typical addition of organic matter and processes of their transformation and decomposition. 2. By the complex of decomposition of the mineral mass and a synthesis of the new mineral and organo-mineral formations. 3. By the single typical character of migration and accumulation of matter. 4. By the single typical structural soil profile. 5. By the single typical way for increasing and maintaining soil fertility.

Subgroups are those soils within the group, qualitatively differing by the manifestation of the basic and imposed processes of soil formation and appearing as transitional stages between groups. Methods to increase and maintain soil fertility within each subgroup are more alike than in the group. In dividing the subgroups the processes associated both with the subzonal and the facies change in natural conditions are taken into account.

Genera are those soils within the subgroup whose qualitative genetic characteristics are caused by the influence of a complex of local conditions: composition of soil-forming parent materials, chemical composition of ground waters, etc., including the properties of the soil-forming substrata acquired through the process of former phases of weathering and soil formation.

Species are those soils within the soil Genera which differ by the degree of the development of the soil forming processes (degree of podzolization, depth and degree of humus erosion, degree of salinization, etc.), and their mutual combination.

The Plenum studied data on the systematics of soils of the taiga-forest belt of European USSR which had been submitted for wide discussion at its first session, and came forth with a comparison of views on several controversial questions.

Changes in the list of soil groups of the taiga-forest belt discussed at the past Plenum of the Committee were suggested only by K. P. Gorshenin, who recommended dividing the podzolic and sod-podzolic soils into independent soil groups.

With respect to the subgroup division of podzolic soils, comments were voiced in behalf of dividing the subgroup of humus-podzol soils prevalent in the southern Baltic region. YE. N. Ivanova and A. A. Zavalishin described these soils as "a facies subgroup" associating the podzol and brown forest soils. Besides the peculiar (original) composition of the organic matter, these soils are often distinguished by a pale-yellow color and it would be preferable to refer to them as "humic-pale-yellow-podzolic".

Several proposals were made to make the subgroup division of podzol-bog soils more complex and to change their names.

In dividing the subgroups the proposal was made 1) to reflect the development of these soils from podzolic to bog (the podzolic-gley-like, podzolic-gley), 2) to show the nature of humidification (the surface-gley, the subsoil-gley), and 3) to indicate the subzonal differences.

The "bog-podzolic" and "podzolic-gley" were proposed as being, on the whole, more rational designations of the group.

In discussing the systematics of sod-forest soils it was suggested that the former name of the sod-carbonate soils be kept in parentheses (rendzinas, humic-carbonates, humo-carbonates) to construct the subgroup division of sod-gley forest soils on the same principles as proposed above for the division of podzol-bog soils (the gley-like and gley soils of surface and subsoil moisture).

The question of the systematics of bog soils again created substantial differences of opinion within the Committee. I. N. Skrynnikova's proposal to study the systematics of bog soils in all the soil zones was adopted.

The systematics proposed for gray forest soils did not meet with opposition. According to the opinion of several members, we must also consider surface and subsoil moisture when dividing the gray forest gley soils into subgroups.

Summing the results of the discussion, I. V. Tyurin emphasized that the scheme of soil systematics considered at the first session of the Committee included only a part of the taiga-forest belt as far as the Urals; the provincial and facies differences within the soil groups were not fully developed or taken into account. The Plenum requested K. P. Gorshenin to present data for dividing the soils of the taiga-forest belt of Western and Central Siberia (outside the permafrost region). The working subcommittee and K. P. Gorshenin were assigned the responsibility of introducing necessary supplements to the proposed scheme for the systematics of the taiga-forest belt, taking into consideration the remarks made at the Committee sessions.

With respect to the schedule of future activities f the Joint Committee on Nomenclature, Sysematics, and Classification of Soils, the Plenum esolved: 1. To prepare a scheme for the systematcs of the salinized soils of the USSR (solonchak, olonetz, solodi) for the next (third) session of the Committee, 2. To complete and coordinate schemes for the systematic division of soils by taiga-forest and chernozem-steppe regions and to study these soils together at the next session of the Committee, in order to arrive at a final decision.

Methods

BORON IN CHERNOZEMS AND GRAY FOREST SOILS OF NORTHERN BULGARIA

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This article presents the results of investigations which were conducted on soil samples collected by the Soviet-Bulgarian expedition in 1947–54,[1] in Northern Bulgaria. Samples of salinized soils of the Karaboazkiy lowland and alluvial-meadow soils of the selection station territory in the Gornooryakhovskiy vegetable district were also studied.

Total boron content and its water-soluble compounds in soil were determined.[2] Preparation was made according to Sinyakova (11). Water-soluble boron was extracted after boiling in water for 30 minutes. It was cooled to room temperature, then filtered. Boron was determined by the distilled microvolumetric method in accordance with Sinyakova's modification (10). Complex acid, formed from boric acid and mannite was titrated according to Bobko (4) in a closed system with methyl red and phenol red as indicators.

Total Boron Content

Data of Table 1 show that chernozems and gray forest soils of Northern Bulgaria contain $2.8 \times 10^{-3}\%$ to $5.3 \times 10^{-3}\%$ of boron. This value is slightly higher than the median value of $3 \times 10^{-3}\%$ found by Vinogradov (6) for soils of European USSR. According to Sinyakova's determinations (9), boron content of podzolic, gray forest soils, chernozems, and chestnut soils of the USSR varies from $2.0 \times 10^{-4}\%$ to $1.2 \times 10^{-3}\%$. The total boron content of Northern Bulgarian soils is larger than that of Central European soils[3].

That chernozems of Northern Bulgaria are high in total boron becomes clear when compared with boron content of chestnut soils ($2 \times 10^{-3}\%$), solonetzic chestnut soils, and sierozems of the USSR. Boron content of Northern Bulgarian chernozems is more like the total boron content of chernozems and chestnut soils of the USA, according to Vinogradov.

The gray forest soils of Northern Bulgaria contain $3.2 \times 10^{-3}\%$ to $3.4 \times 10^{-3}\%$ of boron. Vinogradov (6) and Sinyakova (9) established considerably smaller total boron content ($5 \times 10^{-4}\%$ to $9 \times 10^{-4}\%$) for the gray forest soils of the USSR.

In Northern Bulgaria the salinized soils of the Karaboazkiy lowland contain the highest amount of total boron ($n \cdot 10^{-2}\%$). This is close to that of semi-desert soils (6).

Water-soluble Boron

Soils of Northern Bulgaria contain $1 \times 10^{-5}\%$ to $10 \times 10^{-5}\%$ of water-soluble boron (Table 2). This is close to that in non-salinized, well leached soils of other countries ($n \times 10^{-5}\%$) (6).

Northern Bulgarian chernozems contain $5 \times 10^{-5}\%$ to $10 \times 10^{-5}\%$ of water-soluble boron. Chernozems of the Russian plain contain approximately the same amounts $8 \times 10^{-5}\%$ to $9 \times 10^{-5}\%$ (9). Brasyuk and Zimina (7) found comparable variation in boron content for Ukrainian chernozems.

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[1] Field and laboratory materials on these sections are published by I. N. Antipov-Karatayev and I. P. Gerasimov (3) and others in the monograph: "Bulgarian soils" (1958).

[2] Laboratory worker D. Takova took part in the experimental portion of the work.

[3] According to Vinogradov (6), the total boron content of European soils is as follows: Germany $2 \times 10^{-4}\%$ to $3 \times 10^{-3}\%$; Poland $0.1 \times 10^{-4}\%$ to $3 \times 10^{-3}\%$; Czechoslovakia $8 \times 10^{-4}\%$ to $7.5 \times 10^{-3}\%$; Switzerland $4 \times 10^{-4}\%$ to $1.5 \times 10^{-3}\%$.

Comparing the boron content established by Sinyakova (9) for the gray forest soils of the USSR with that of Bulgaria, we find that the atter are richer in water-soluble boron.

The alluvial-meadow soils of the Oryakhovitsa River vegetable district are comparatively rich in water-soluble boron (9 × 10^{-5}%) and do not differ in this respect from carbonate chernozems. The salinized soils of the Karaboazkiy lowland are very rich in water-soluble boron (2.2 × 10^{-4}%). Sinyakova (9) established a similar value (1.1 × 10^{-4}% to 2.7 × 10^{-4}%) for the water-soluble boron content of chestnut solonetzic soil, solonetz, and solonchak of the USSR. Blasyuk

TABLE 1

Total boron content of chernozems and gray forest soils of Northern Bulgaria

Soil and location	Horizon	Depth, cm.	n 10^{-3}B		Amount of boron in hor. A_1 in % of its amount in hor. C (calculated for humus-free and carbonate-free soil	Investigator
			100 gm. soil	100 gm. carbonate-free and humus free mass		
Geomorphological region—Danube hilly plain						
Carbonate chernozem on loess; Krumovo village	A_1	0–18	4.1	4.3	69	
	A_3	37–50	3.2	3.6	—	
	C_2	170–180	4.8	6.2	—	
Same, virgin soil on loess; Zlokuchene village	A_1	0–10	4.4	4.8	—	
Typical chernozem on loess; Knezha town	A_1	0–10	3.9	4.0	—	
Leached chernozem on pliocene clays; Madan village	A_1	0–10	3.5	3.6	68	
	C_1	190–200	4.6	5.3	—	
Same, on loess clay material; Pavlikeni town	A_1	0–12	3.6	3.7	86	
	C_1	100–111	3.7	4.9	—	
Same, virgin soil on loess; Pordim village	A_1	0–10	4.5	4.9	120	
	C_2	160–170	3.3	4.1	—	
Geomorphological region—Ludgorskoye plateau						
Carbonate chernozem on loess-like clay; Suvorovo village	A_1	0–10	3.6	3.9	78	H. Matveyev
	C_2	150–160	3.6	5.0	—	
Same, on cretaceous carbonate parent material; Fisek village	A_1	0–10	5.3	5.7	77	
	C_2	126–155	5.3	7.4	—	
Leached chernozem on loess-like clay loam; Chiflik sample	A_1	0–10	2.8	2.9	76	
	C_2	190–200	3.1	3.8	—	
Geomorphological region—Yuzhnodobrudzhanskoye plateau						
Typical chernozem on loess; Paskalevo village	A_1	0–22	3.9	4.1	—	M. Yolevskiy
Leached chernozem on loess; Dobrudzhanskiy Institute	A_1	0–10	4.2	4.3	88	
	C_1	160–170	4.3	4.9	—	
Geomorphological region—Balkans						
Dark-gray forest soil on clay materials of weathered cretaceous deposits; Banitsa village	A_1	0–10	3.4	3.6	90	Asp. Yanakiyev
	B_1	50–60	3.3	3.4	—	
	C_2	140–150	3.2	4.0	—	
Same, village Chiren	A_1	0–10	3.2	3.3	—	
Same on brown clay loams; Svetlen village	A_1	0–10	3.4	3.5	90	
	C_1	115–125	3.4	3.9	—	
Geomorphological region—Accumulative terrace of Danube						
Alluvial-meadow soil, solonchak salinized virgin soil; Karaboazkiy lowland	A_1	0–10	16.1	18.1	—	Khr. Trashliyev and T. Ovcharova

TABLE 2

Content of water-soluble boron in arable horizon of chernozems and gray forest soils of Northern Bulgaria

Soil and location	Horizon	Depth, cm.	pH	$n\cdot10^{-5}$ % Boron	Investigator
Geomorphological regions—Danube hilly plain and adjoining part of pre-Balkans					
Carbonate chernozem Galovo village	A_1 plowed	0–10	8.4	9.8	
Same; eroded Baniska village	"	0–25	8.5	4.3	
Typical chernozem; Knezha town	"	0–10	7.2	7.2	
Leached chernozem; Pavlikeni town	"	0–12	7.1	7.3	
Same; Madan village	"	0–10	7.2	7.0	
Same; Patresh village	"		6.6	4.9	Yemil Angelov
Podzolized chernozem; Okhoden village	"	0–12	6.0	5.1	
Dark-gray forest soil; Banitsa village	"	0–10	6.6	3.4	
Gray forest soil; Okhoden village	"	0–10	6.3	4.1	
Same; Stoyanovo village	"		6.0	4.9	
Light-gray forest soil; Yelena town	"	0–10	6.5	2.9	Khr. Trashliyev and G. Dimitrov
Light-gray forest undeveloped soil; Zanozhene village, waste land	"	0–10	6.0	1.1	
Alluvial-meadow soil; Gorna Oryakhovitsa town	"	0–10	8.0	9.0	M. Milcheva
Geomorphological regions—Ludogroskiy plateau and adjoining part of pre-Balkans					
Carbonate chernozem; Suvorovo	A_1 plowed	0–10	8.4	8.6	
	A_2	45–55	8.4	5.5	
	A_3/B_1	80–90	8.3	4.5	
	B_2/C_1	115–125	8.4	4.8	
	C_2	150–160	8.7	11.1	
Typical chernozem; Fisek village	A_1 plowed	0–10	7.5	8.7	
Leached chernozem; Seyachi village	"	0–10	7.0	5.1	K. Mateyev
Dark-gray forest soil; Svetlen village	"	0–10	6.7	5.8	Asp. Yanakiyev
	A_2	26–36	6.7	4.7	
	A_3	44–54	6.7	4.5	
Dark-gray forest soil; Kichenitsa village	A_1 plowed	0–10	6.2	10.0	"
Same; Svetlen village	A_1 plowed	0–10	6.0	4.3	"
	A_3/B	40–50	6.0	6.3	
	B_2	54–75	6.1	2.0	
	B_3	75–111	6.3	3.3	
	C_2	145–155	8.3	2.5	
Gray forest soil; Svetlen village	A_1 plowed	0–10	5.6	3.7	"
	B_1	25–35	5.7	2.8	
	B_2	48–58	5.9	2.1	
Geomorphological region—Yuzhnodobrudzhanskoye plateau					
Typical chernozem; Paskalevo village	A_1 plowed	0–12	8.1	9.4	
Leached chernozem; Blatnitsa village	"	0–10	6.5	5.1	
Same; Dobrudzhanskiy Institute	"	10–10	7.0	4.7	
Geomorphological region—Danube accumulative terrace					
Alluvial-meadow soil salinized; Karaboazkiy lowland	A_1 plowed	10–10	7.6	22.7	

and Zimina (7) established this for similar soils of the Ukraine.

Data on the distribution of water-soluble boron in the soil profile (Table 2) show that the content decreases downward in chernozems and gray forest soils. When compared to the boron content of horizon A_1, a slight increase in water-soluble boron is observed in the lower horizons of some arable gray forest soils.

Discussion of Experimental Data

Parent material of northern Bulgarian soils is rich in boron. This is evident from the data on total boron content of horizon C of the soils investigated. In horizon C, a great amount of total boron is found in chernozems that were formed on oess and chernozems and gray forest soils developed on pliocene clays, Cretaceous carbonate parent material, and clay and clay loam weathered materials of Cretaceous rocks. The boron richness of the parent material in the majority of Northern Bulgarian soils is apparently due to the marine origin of sedimentary Cretaceous, and other, rocks[4].

From the geochemical point of view a greater part of Northern Bulgarian territory can be assigned to the geochemical boron province described by A. P. Vinogradov that encloses the shores of the Azov and Black Seas, the northern shores of the Caspian Sea and the Aralo-Caspian lowland. Vinogradov emphasizes that these regions of the USSR are rich in boron and are located within the boundaries of the Mediterranean geosyncline, which, undoubtedly, is also true of Northern Bulgaria (6). If one accepts the aeolian hypothesis of loess formation in Northern Bulgaria (8) then it is possible to connect the boron richness of all Northern Bulgarian soils with the sedimetary rocks of the Cretaceous age. The ancient volcanic activity in the Old plain should have had a significant role in this.

Our tentative calculations based on tourmaline (2) and boron content of horizon A_1 of village Kromovo chernozem, show that somewhat more than 4/5 of the total boron content of chernozem on loess should be present in tourmaline form. On the basis of these calculations we can assume that a small portion of the total boron content of Krumovo chernozem (on loess) enters into the composition of other boron-containing minerals. This deduction agrees with the investigations of Robinson, Whetstons, and Byers (15) who have shown that some other soil minerals besides tourmaline contain boron.

Weathering of the majority of boron-containing minerals, and especially of tourmaline, is very slow[5]. Clay formation and weakly-expressed podzolization of Northern Bulgarian chernozems and gray forest soils cannot effect a stronger disintegration of highly-stable, boron-containing minerals. Boron freed from mineral combinations is neither retained in weathering products nor in humus and is leached from the soil (12, 5, 13). Northern Bulgarian soils have large amounts of boron owing to the stability of boron-containing minerals. The following relationship can be observed: the change of total boron content in parent material (horizon C) brings about a corresponding change in boron content of horizon A_1. Difficulties in freeing boron from minerals and the strongly expressed migration of freed boron explain the absence of differentiation of its total amount in horizons A and B of gray forest soils. This also explains minute differences in total boron content between subgroups of chernozems, gray forest soils and similar soils of separate geomorphological regions.

Loess, and soils developed on it, are not richer in boron than the parent material and soils of the pre-Balkan plain, which were developed on weathering materials of pliocene clays and Cretaceous sedimentary rocks. The soils richest in boron were formed on solid Cretaceous carbonate rock, which is richest in boron content and undergoes leaching.

Soil boron contents are reduced to some degree by biochemical processes and atmospheric circulation (6.14). Precipitation considerably replenishes boron in the soil, (13) but the total amount of boron in the upper horizons of Northern Bulgarian soils is less than in horizon C. This is well substantiated by the data from Table 1 (converted into carbonate-free and humus-free soil). The boron content is less in horizon A_1 evidently because considerable amounts of boron are removed by crops without compensation by the use of manure and salts. This is why we find horizon A_1 in the virgin soil of Pordim village to be richer in boron.

Data from Table 1 show that the boron content of horizon A_1 as a percentage of its content in horizon C increases from slightly leached soils (carbonate chernozems) to more strongly leached soils (gray forest soils). This pattern can be explained by the fact that boron is removed from C horizon in leached chernozems and gray forest soils, but accumulates in C horizon of carbonate chernozems. If this pattern were traced in soil samples completely similar in agrotechnological history,

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[4] Easily-soluble boron compounds are known to accumulate in sea water and enrich sedimentary parent material with boron (6).

[5] According to Stahlberg (16) tourmaline stands next to quartz in its rate of weathering, hence it is a mineral that liberates very little boron. Goldschmidt (14) also assigns tourmaline to the group of relatively non-soluble and hard minerals, such as quartz and zircon.

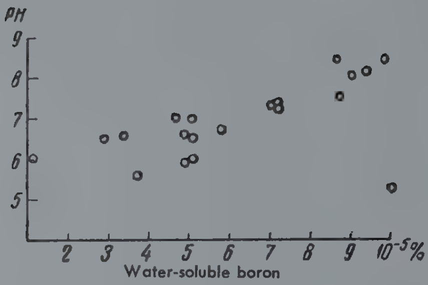

FIG. 1.—Correlation between pH and water-soluble boron content in soils of Northern Bulgaria.

the resultant data could probably be even more significant.

From the material examined it becomes clear that there is a similarity between the boron content of sierozems distributed in the geochemical boron province of the USSR (described by Vinogradov [6]), and the boron content of chernozems of Northern Bulgaria. We had assigned these soils to the same geochemical province, but USSR chernozems do not belong here. They are poorer in boron content than the Bulgarian chernozems, even though the latter are more strongly leached and more clayey. The boron content of Bulgarian chernozems is similar to that of USA chernozems, which are distributed within the boundaries of the North-American Andean syncline.

The large boron content of salinized alluvial-meadow soils in the Karaboazkiy lowland (accumulative terrace of the Danube) can be explained by the processes of greater water evaporation from the soil surface in the presence of a high ground water table and the inflow of salts from pliocene salinized deposits of the coastal zone. These processes resulted in the accumulation of boron compounds that, in time, are transformed into a mineral form nonsoluble in hot water. Therefore, the boron content of the foregoing soils is higher than that of well-leached soils of the geomorphological regions of the Danube plain, Ludogorskiy and Yuzhnodobrudzhanskiy plateaus, and pre-Balkans.

Variation in the content of water-soluble boron is connected with the genesis of Northern Bulgarian soils. Boron decreases in the genetic soil series starting from carbonate and typical chernozems to leached chernozems, then further to gray forest soils. This is because of the similarly increasing intensity of leaching processes. Also, equilibrium between water-soluble and nonsoluble boron compounds is established slowly. The amounts of water-soluble boron are higher in carbonate and typical chernozems inasmuch as these soils contain larger amounts of boron.

TABLE 3

Boron mobility in soils of Northern Bulgaria

Soil and location	Water-soluble boron in % of the total boro
Carbonate chernozem, arable; Suvorovo Village	2.5
Carbonate chernozem, arable; Suvorovo Village Hor. C_2	3.1
Typical chernozem, arable; Knezha Town	1.8
Typical chernozem, arable; Paskalevo Village	2.3
Leached chernozem, arable; Pavlikeni Town	1.9
Leached chernozem, arable; Dobrudzh. Institute	1.2
Dark-gray forest soil, arable; Banitsa Village	0.9
Dark-gray forest soil, arable; Svetlen Village	1.2
Dark-gray forest soil, arable; Svetlen Village Hor. C	0.7
Alluvial-meadow soil, salinized, arable	1.4

Parallel to the increase of moisture in Northern Bulgarian soils, their pH values decrease. Therefore, certain correlation between the water-soluble boron content and the pH value was expected. Figure 1 shows that this relationship, often observed in other soils, (17 and others) is also characteristic of Northern Bulgarian soils. The scattering of points on the graph can be explained by the differences in total boron content by and the texture of the soil investigated. In several cases, the scattering of points is evidently due to the migration of water-soluble boron along the profile. This is not closely related to changes in the pH value.

Differentiation of water-soluble boron content in the horizons is unexpressed, or weakly-expressed because total boron contents are evenly distributed along the profile, and also because, as the result of the soil formation process, the secondary boron compounds which could replace its water-soluble fraction do not accumulated in significant amounts (Table 3).

Table 3 shows that water-soluble boron in the arable layer of chernozems and gray forest soils constitutes 0.9% to 2.5% of total boron. Boron mobility is higher in chernozems than in gray orest soils owing to the previously mentioned ifferences in the leaching intensity.

Conclusions

1. Chernozems of Northern Bulgaria contain .8 $\times 10^{-3}\%$ to 5.3 $\times 10^{-3}\%$ of boron. Gray orest soils contain 3.3 $\times 10^{-3}\%$. The soils richest n boron in Northern Bulgaria are the salinized oils of the Karaboazkiy lowland (n $\times 10^{-2}\%$).

2. Chernozems of Northern Bulgaria contain $\times 10^{-5}\%$ to 10 $\times 10^{-5}\%$ of water-soluble boron. arbonate and typical chernozems of Northern ulgaria contain more water-soluble boron (7 $\times$ $0^{-5}\%$ to 10 $\times 10^{-5}\%$) than do leached and podolized chernozems (5 $\times 10^{-5}\%$ to 7 $\times 10^{-5}\%$). ray forest soils contain 3 $\times 10^{-5}\%$ to 5 $\times$ $0^{-5}\%$. Alluvial-meadow soils of the Oryakho-itsa River district are relatively rich in water-oluble boron (9 $\times 10^{-5}\%$), while salinized soils f the Karaboazkiy lowland are the richest 2.2 $\times 10^{-4}\%$). Eroded carbonate chernozems are oorer in water-soluble boron, than are similar, on-eroded soils.

3. From the geochemical point of view, the ter-itory of Northern Bulgaria can be assigned to the oron geochemical province described by A. P. inogradov, which encompasses the shores of the lack and Azov Seas, and the northern shores of he Caspian Sea. The parent material of Northern ulgarian soil is rich in boron because the area is omposed of sedimentary residual parent ma-erial of the Cretaceous age. More than 4/5 of the otal boron content of chernozems developing on oess is found in the tourmaline form. There are light differences in boron content between the ubgroups of chernozem and the species of gray orest soils within the boundaries of one geomor-hological region, and also between geomorpho-ogical regions. These are explained by the stabil-ty of boron-containing minerals and by the imilar boron content of their parent material.

4. The large boron content of chernozems and ray forest soils of Northern Bulgaria is regarded s a provincial soil peculiarity. Considerable dif-erences were established in the boron content of oils of the Danube soil province, and of cherno-ems and gray forest soils of the Russian Plain oil province. An explanation of these differences s given.

5. The decrease of water-soluble boron from arbonate and typical chernozems to leached cher-ozems, and, further, to gray forest soils is due hiefly to the intensity of the leaching processes. The higher content of water-soluble boron of salinized soils is caused by the supply of ground waters from salinized pliocene deposits.

6. There is a difference in the boron supply of different soil groups, subgroups, and varieties. However, the main soil variants of Northern Bulgaria do contain neither too much nor too little water-soluble boron to cause sharp marked deficiency or excess of boron and resultant plant diseases.

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WATER PERMEABILITY OF FROZEN SOIL AT KULUNDA STFPPE

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THE water permeability of frozen soil has interested many investigators. Shalobanov (17) seems first to have expressed the likelihood of water seepage through frozen soil. With a lysimter Hemmerling (4) determined permeability f fine-textured soils and obtained data confirmng the fact of much infiltration of soil by thaw waters. Unfortunately, this investigator does not ive the data for infiltration coefficient and for oil condition (whether frozen or thawed). Kahinsky (7) proved by field experiment that rozen soil does absorb water. In Kachinsky's xperiments, water penetrated through a frozen soil layer 33 cm. thick, mainly through plant root channels, wormholes and other cavities. Accordng to this investigator, the watersoaked frozen oil forms a solid ice layer impermeable to water. Srebrianskaya (14) carried out field experiments on the study of water permeability of rozen soils at Baraba, and concluded that frozen oils are 10 times less permeable than thawed oils.

Williams (2) believes that frozen structured soil is permeable to water. According to Sabo (13), frozen soil lets in water only when the soil moisture content is not over 80% of its field content (its lowest, according to A. A. Rode).

The majority of investigators believe that low water permeability of frozen soils is inevitable. But a number of authors (1, 8, 11, 16) are of a different opinion. The same soil may become in some cases of freezing completely impermeable to water, while in others it absorbs water quite well. We decided after direct observations that the frozen soil of shallow estuaries that fill with melting ice and snow begins to absorb water only several (in Kulunda, 5 to 6) days after the estuary is filled. The absorption process is easily visible; it is accompanied by air bubbles on the water surface.

We have set up experiments on the water intake into frozen soils in cultivated and virgin lands of Kulunda steppe (Ob River plateau). Our work on water intake of frozen soil was carried out in late March and early April, 1954–1957, in the Rodinsky district, Altai region. The topsoil of our experiment plots consists mostly of southern-type chernozem of medium clay loam combined with solonetz and solonchak[1]. The ground water table is at a depth over 5 to 6 m.

Water permeability of frozen soil was determined in 1954 following a somewhat modified method by Boldyrev. According to this method, pits 30 x 30 cm. were dug in the frozen ground. A constant water level 5 cm. high was kept in the pits. The time required for the water to enter the soil and the amount of water used (from nearby depressions) were measured. The temperature of water was held at zero by systematic additions of snow. Determinations for water intake were replicated three times.

Permeabilities for frozen soil were determined by the Nesterov method in the spring seasons of 1955 to 1957. This method excludes the effect of water seepage by capillary attraction laterally and upward—an important factor in permeability determinations for thawed soils. Determinations of moisture and temperature of the soil were made simultaneously. Resistance thermometers were placed at a depth of 10, 20, 30, 40, 50, 100 and 160 cm. Soil moisture during experiments was rather low (see Table 1).

Data for rate of water intake into frozen soil were completed in spring, 1954, following the Nesterov method. The figures show little variation. The water intake rate is identical for experiments 1 and 2. The process, characterized by sporadic jumps and delays in intake, apparently is due to the number of cracks in the test area (Table 2). The amount of water entry by the frozen soil greatly depends on the initial moisture content of the soil before it was frozen (Table 3). The temperature of the upper soil horizons during experiments was from minus 0.8° C. (in 1954) to minus 1.2° C. (in 1956).

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[1] The soil names are taken from the paper by K. P. Gorshenin (5).

TABLE 1

Moisture content of frozen soil (southern chernozems) in different sections

Depth, cm.	Plowed land		Virgin land	
	In percent			
	Dry soil weight	Minimum moisture content	Dry soil weight	Minimum moisture content
March 30, 1954				
0–10	22.50	97.8	21.40	93.6
10–20	17.82	82.7	17.12	80.5
20–30	15.14	72.1	14.17	66.7
30–50	10.87	52.2	9.92	51.4
50–70	8.12	40.7	8.87	46.7
70–100	7.15	37.4	8.21	41.3
March 26, 1955				
0–10	22.00	96.1	21.80	94.8
10–20	22.20	96.5	22.10	96.1
20–30	20.40	88.8	19.60	85.4
30–50	18.10	78.7	17.90	77.8
50–70	14.30	62.2	13.20	57.1
70–100	13.10	57.1	13.15	56.8
March 17, 1956				
0–10	15.10	65.6	14.10	61.2
10–20	13.20	57.3	13.80	59.9
20–30	13.10	56.8	12.10	52.6
30–50	9.63	41.8	10.10	43.8
50–70	8.10	35.2	8.00	34.7
70–100	7.25	31.5	7.10	30.9

Results of observations on water intake into frozen soil, completed in spring 1955 for the same test areas but with higher soil moisture contents, are very similar to those for 1954. They are given in Table 4.

Within six hours' time, only 24.5 mm. of water entered the soil, as shown in these experiments. The surface remained frozen in the other experiments and almost no entry took place.

Experiments have thus confirmed the relatively low permeability of frozen southern chernozems of medium clay loam during the season of melting snow. Entry of water ceases completely when even a slight crust of ice is formed at the bottom of the test pit. Such a crust appears at the least drop of water temperature below zero—a rather frequent occurrence in Western Siberia.

The entry of water from melted snow seldom increases as the soil thaws out. Observations on thawing and rate of water intake were carried out on virgin land (meadow) in the spring of 1954. No snow was added to the thaw water. The temperature of thaw water rises abruptly in the sun, and the walls of the test pit gradually thaw out. Thus the bottoms of the pits are freed of ice at different depths. Penetration of water varies accordingly (Table 5).

The change in coefficient of water entry by the soil can be expressed as follows (after Kostyakov, 9):

TABLE 2

Total intake of thawed water into frozen soil, a recorded in field studies for Spring, 1954

Time from start of experiment, minutes	Total intake, mm.			
	April 10 (plowed land)		April 12 (virgin land)	
	Test No. 1	Test No. 2	Test No. 1	Test No. 2
17	—	—	—	2
29	2	—	—	6
40	4	—	5	8
54	6	—	7	9
62	8	1	—	11
72	9	—	9	—
83	12	3	12	15
91	13	5	—	18
114	—	—	15	19
124	14	7	19	21
134	15	10	21	27
144	—	10	25	32
154	—	—	—	37
165	—	12	29	42
174	18	13	37	56
184	21	15	44	58
200	23	17	47	59
240	29	20	54	62
280	31	23	61	64
320	35	24	63	65

TABLE 3

Absorption of thawed water by frozen soil (southern chernozem, clay loam) with varying soil moisture content

Date	Test No.	Type of land	Average moisture content of arable layer (22 cm.), %	Increase in moisture storage of soil during experiment, mm.
1954 April 4	2	Virgin (hayfield)	17.19	22.0
April 5	6	Plowed (crosswise plowing)	24.24	0.12
1956 March 25	5	Virgin (hayfield)	12.15	49.4
March 27	7	Plowed (crosswise)	13.85	31.6

$$K_t = \frac{K_0}{t^\alpha} \quad (1)$$

vhere K_t is the coefficient of water entry by soil t the moment t, K_0 is the coefficient of water ntry by soil at the initial moment; t—the time rom start of experiment; α—index of rate charcterizing the shape of curve for change in entry oefficient, in relation to time.

Our observations show that frozen medium lay loams (southern alkaline chernozems) have he α-coefficient equal, on the average, to 0.40 Table 6).

By knowing the rate of change in coefficient f water entry by frozen soil in relation to time, ve can determine the total amount of water (h) ntered the soil in a calculated time interval:

$$h = \int_0^t K_t \, dt = \int_0^t \frac{K_0}{t^\alpha} \, dt = \frac{K_0 t^{1-\alpha}}{1 - \alpha} \quad (2)$$

Therefore the formula for frozen medium clay oam (southern alkaline chernozems) at Kulunda steppe, Ob river plateau, will look as follows:

$$h = \frac{K^0 t^{1-\alpha}}{1 - \alpha} = 1.67 K_0{}^m t^{0.6} \text{ mm.} \quad (3)$$

vhere $K_0{}^m$ is the initial coefficient of water entry y frozen soil in mm. per hour.

If it is impossible to make this determination n wintertime, it is made in summer, with the proper corrections.

If the soil has thawed out entirely at the start f flow from snow melt, then $K_0{}^T$ is used instead f $K_0{}^m$ (the initial saturation coefficient of thawed soil). However, this is a very rare occurrence in Western Siberia where the winters are mild and the snow cover very deep. But if the frozen soil bsorbs water, and the entry coefficient has been determined in summertime, the correction coefficient β must be introduced in the formula. The preceding combination will then appear as ollows:

$$h = 1.67 \beta K_0{}^T t^{0.6} \quad (4)$$

The coefficient β changes under conditions of Kulunda steppe (Ob River plateau) within 0.00 o 0.37 limits, depending on moisture content and degree of cementation of frozen soil. This relation can be determined approximately by experiments described previously (Table 7). However, it requires further refinement through more extensive experiments to determine the effect of temperature with soils of various forms of porosity.

TABLE 4

Water entry into frozen soil (new land), recorded for 1955

Time from start of observations, minutes	Total intake, mm.	Intake rate, mm. per minute	Rmearks
20	4.20	0.21	At the end of experiment, an ice crust had formed on water surface in the test pit
40	5.60	0.14	
60	7.80	0.13	
80	10.4	0.13	
120	14.4	0.12	
160	16.0	0.10	
220	17.6	0.08	
260	18.2	0.07	
300	21.0	0.07	
360	24.5	0.07	

TABLE 5

Total water entry in soil thawed to varying depth from field measurements for 1957

Duration of water entry, minutes	Water entry, mm.				Remarks
	Test Nos.				
	1	2	3	4	
10	1.0	3.0	4.5	21.0	Soil thawed during experiment Tests: No. 1–25 mm. No. 2–100 mm. No. 3–180 mm. No. 4–350 mm.
20	2.0	4.0	7.0	27.0	
30	2.0	4.0	8.0	31.0	
40	2.0	7.0	9.5	39.0	
50	2.0	7.5	11.0	44.0	
60	3.0	9.5	19.0	49.0	
70	3.0	11.0	23.0	54.0	
80	4.0	11.0	26.0	61.0	
90	4.0	13.0	32.0	64.0	
100	4.0	15.0	33.0	67.0	
140	6.0	17.5	41.0	72.0	
180	7.5	19.0	45.0	78.0	
220	8.0	21.0	49.0	80.5	
260	8.5	22.5	54.0	87.0	
300	9.0	27.0	59.0	89.0	
340	10.5	29.0	67.0	94.0	

TABLE 6

Change in index of α-degree in field tests measuring permeability of frozen medium clay loams (southern chernozem)

Type of land	Soil horizons, cm.					Average
	10	20	35	45	55	
Plowed	0.27	0.34	0.38	0.41	0.47	0.38
Virgin	0.31	0.37	0.43	0.47	0.53	0.42

In planning for the utilization of water resources, it is important to estimate the changes

TABLE 7

Relation of β-coefficient to moisture content in frozen medium-clay loams (southern chernozem) under conditions at Kulunda steppe, Ob River plateau

Soil moisture in % of minimum moisture content	95.0	85.0	70.0	60.0	40.0
β-index	0.00	0.03	0.13	0.24	0.37

TABLE 8

Relation of coefficients for runoff from small basins and percent of plowed land to fallow land (Andreyevsky area, Novosibirsk district, 1956)

Name and description of water basins	Area of basin, sq. km.	% of plowed to fallow land	Runoff coefficient
Kuznetsov Lake (pasture prairie, clay loam)	2.56	15.0	0.60
Lake Ryamovoye (hayfield, clay loam)	0.89	20.0	0.49
L. Gor'koye (Bitter Lake) No. 1, (corn stubble, clay loam)	6.24	60.0	0.37
L. Gor'koye No. 2, (wheat stubble and virgin land)	7.68	40.0	0.52
Mokhnatkina Lyaga (hayfield, clay loam)	1.24	0.00	0.67
1st stratum of shallow estuary (crosswise plowing, clay loam)	0.57	100.0	0.127

TABLE 9

Ratio of runoff coefficient to percent of fallow to plowed land (Pankhrushiklin district, Altai Region, 1957)

Name and description of water basin	Area of basins, sq. km.	% of plowed to fallow land	Runoff coefficient	Remarks
Dell No. 1 (corn stubble, clay loam)	3.25	50.0	0.38	Ice crust, 1.5 to 2 cm. thick, observed on soil surface
Creek No. 1 (crosswise-plowed land)	0.15	100.0	0.21	
Creek No. 2 (virgin land)	0.08	00.0	0.68	
Creek No. 3 (wheat stubble, virgin land)	0.07	30.0	0.59	
Lake Mitino (wheat stubble and virgin land)	1.40	25.0	'0.62	

in amounts of drainage caused by reclamation work on virgin and fallow lands. Reshëtnikov (12) found in his experiments at the Valday hydrological station that the coefficient for amount of spring runoff along a plowed slope was much less than along a slope of virgin land; this hel true for two years out of three. Ooryvayev (15 came to the same conclusions for Valday. H continues to say that the amount of water runoff along plowed slopes greatly depends on grad of slope: the flow from gradual slopes is one-hal or only one-third of that from medium stee slopes.

Garyugin (3) records a great decrease in surface runoff following plowing of fallow lands i the Azov (Sea) area. Kuznik (10) finds that th flow from the plow layer and its turned ove layer in the Trans-Volga region is absent even i seasons of high water. The soils here are chernozem and dark chestnut. Flow from the turne over layer is observed only when the slope is o the 0.01 category and the land is plowed lengthwise of it. Large amounts of drainage accumulate in the old plowed section. A striking increas in amount of runoff is observed from compacte fields covered with mixed grasses, even in dr years. This statement by Kuznik disagrees with Kabanov's findings (6). He believes that th runoff from the field under perennial grasses wa much less than that from fields lying fallow o planted to winter crops.

We have recorded our observations on runof from slopes along the shallow estuaries of Salomatkina Lyaga (Northern Kulunda) at th natural boundary and also along the hills enclosing lake depressions. Our records for spring 1956, show that almost all the spring runoff was from fields under wheat and corn stubbl and from virgin land under pasture. There was practically no runoff from fallow field (Table 8).

Thus it seems very unlikely that the basin of shallow estuaries will be filled with thawe waters during the spring season, when each basin is thoroughly plowed up for fallow. Hence the need to watch the accumulating snow in winter and to hold it artificially in estuaries and estuary basins, so as to guarantee an extra supply of soi moisture in case the runoff from the slopes is no sufficient.

Let us examine the material at hand for 1957 for the Panshikha river basin, Central Kulunda Flow was observed in the natural dell and in three creeks. The snow began to melt in early April. The runoff started April 9th, as soon as positive temperatures were recorded for the three observation dates. It terminated on April 23r the creeks and on May 5th for the dell. The ring of 1957 was late and long (advective thaw-g). Measurements of runoff are given in Table 9.

Our studies leave no doubt that the differences amount of runoff from small water basins are e only to differences in size of agricultural eas. Otherwise the basins are quite the same relief and soil conditions. We find it advisable differentiate between runoffs from plowed and n-plowed areas in our estimates of changes in ter flow, caused by reclamation work on virgin d fallow lands at Kulanda.

Conclusions

1. The amount of water entry from melted ow into clay loam soil (southern alkaline cherzem) can be determined by formula (3), proded the soil is water-permeable and the entry not obstructed by icing of the moisture front.

2. Soils in which all the pores are filled with from the presence of excess moisture before ezing are impermeable to water until the time en thawing begins. Permeability of frozen edium clay loam (southern chernozem) is reored when its moisture content falls below 60 65% of the field moisture content (which is e lowest, according to A. A. Rode).

3. Soils that retain over 50% of their porosity ow free access to water regardless of their mperature.

4. Cross plowing regulates surface runoff tter than fallow land or stubble fields, or fields der winter crops. The runoff coefficient (1957) plowed fields was equal to 0.21; for virgin nd (hayfield) it was 0.68; and for corn stubble lds, 0.38.

5. It is advisable to make separate estimates surface runoff from plowed and non-plowed eas when recording changes in surface flow used by reclamation work on virgin or fallow nds.

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WATER REGIME OF VIRGIN STEPPE AREAS IN THE SAND OF TEREK AND KUMA RIVERS

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The sands of Terek and Kuma consist of four areas: Terek, Bazhigan, Tereklin and Kuma (5), and are located in the southwestern part of the Caspian plain within the boundaries of the Nogay steppe. The sands consist of barren and overgrown areas, and also areas of virgin sandy steppe.

The climate of the region is dry, hot, generally continental but somewhat tempered by the Caspian Sea. Precipitation is from 250 mm. in the northeast to 350 mm. in the southwest. Precipitation from October to March is 110 to 130 mm. The basic factors governing the water regime of the sands and sandy soils are: climate, depth of water table, vegetation, physical properties of the soil. These factors have a great range of variation among the different areas and also on the same area.

Virgin areas are characterized by three basic types of water regime: non-leached areas, leached areas, and seepage areas (8). The greater area (70%) between the Terek and Kuma rivers consists of non-leached soils, the smallest area (1%) has seepage. The force of capillary attraction and the depth of soil saturation from rainfalls varies depending on the texture of the soils. The kind of water regime encountered on the different areas varies accordingly, depending on the different levels of the water table.

In the coarser-textured Terek sands (made up mostly of medium and fine fractions), the seepage type corresponds to a ground-water depth of 100 to 110 cm.; the leached type corresponds 110 to 260 cm., and the non-leached to over 260 cm. In the finer-textured sands of Bazhigan and Tereklin (consisting of fine particles of sand and silt), the seepage type is formed when the ground-water table is up to 250 cm., the leached when it is 250 to 400 cm., and the non-leached when it is over 400 cm. The middle position is occupied by Kuma fine-textured sands.

The equation by Rode (7) was used to estimate the water balance, B_1 :

$$B_1 = B_0 + [\text{Ppt.} + \text{C(ondensation)}$$

$$+ \text{G(round water)}] - [\text{T(ranspiration}$$

$$+ \text{E(vaporation)} + \text{R(unoff, surface)}$$

$$+ \text{S(ub surface flow)} + \text{P(ercolation)}]$$

If we exclude the factors of ground-water tabl surface and subsurface runoff and condensatio the equation is shortened as follows:

$$B_1 = B_0 + \text{Oc} - (\text{D} + \text{Evap.}),$$

$$B_1 = B_0 + \text{Ppt.} - (\text{T} + \text{E})$$

hence the transpiration (T) of the herbaceou plant cover equals:

$$D = (B_0 - B_1)$$

$$+ \text{P(recipitation)} - \text{E(vaporation)}.$$

The moisture content (B_0 and B_1) of the so was determined once each month by the accepte method to a depth of 4 m., and once per seaso down to the ground-water level. Precipitation wa recorded at the rain-gauge stations located 80 m. away from the main hydrological statio Evaporation (E) was determined by indire method as follows.

The main hydrological station where studie of the non-leached type of water regime wer carried on, is located on a sloping hilly plai among the sands of Bazhigan. Its vegetatio consists of feather grass (*Stipa*) combined wit *Festuca*(sulcata) with the addition of ephemer and ephemeroids. According to Shiffers (9), th yield of hay is 4.5 centner per hectare.

The soils are chestnut, over finely texture sandy and pulverulent ancient alluvial deposit of loess. Soil bulk density is 1.44 to 1.50 gms per cc.; HB (field moisture capacity = 11% BPK (lower capillary-flow moisture) = 6% BZ (wilting moisture) = 3%. Water table is a the depth of 9.2 m.; its dry residue is 10 gram per liter.

There was not one actual case of complet saturation recorded at the weather station men tioned for 1946 to 1951 and 1953 to 1956. steady supply of moisture begins to reach th

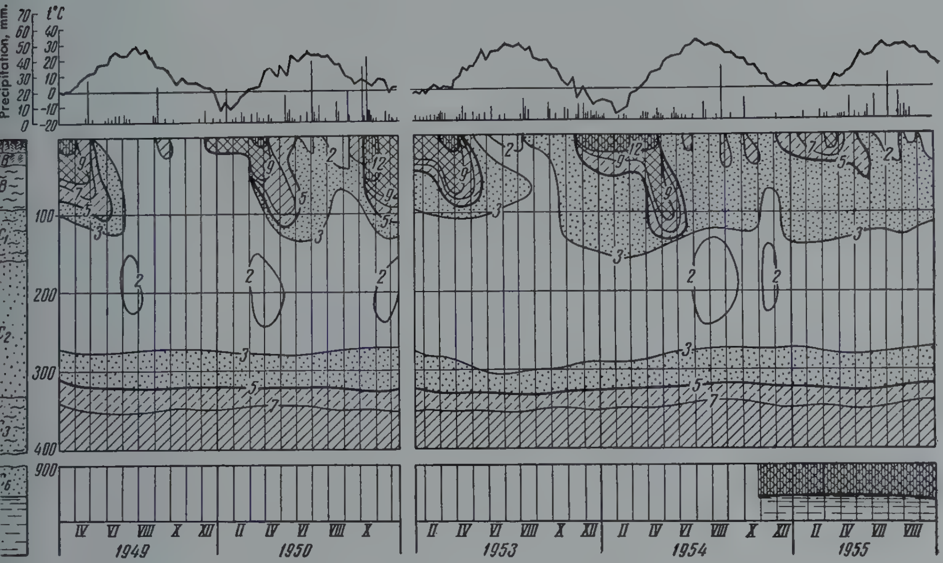

FIG. 1.—Dynamics of soil moisture on virgin steppe of Bazhigan area. Chromo-isopleths given in % r absolutely dry soil.

ed-out upper soil horizons in September or tober (Fig. 1). By winter precipitation moisre reaches down to a depth of 30 to 50 cm. At at time, saturation takes place only during aw. In March, when the average daily (24-hr.) mperatures pass the O° C. mark, the moisture on penetrates to a depth of 100 to 150 cm. By ay and June, the saturated soil strata have en quickly depleted of moisture down to the wilting percentage (Table 1), owing to root suction. By July, the only plants left growing are the xerophytes (*Stipa*) and those with a deep root system (*Alhagi camelorum* and licorice (*Glycirrhiza glabra*)).

TABLE 1

isture content of soil (average for many years) n virgin steppe areas of the Bazhigan area for eriods 1946–1950 and 1953–1955 (non-leached type f soil)

th, n.	Months									
	Jan.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
5	19.3	14.0	6.3	5.1	2.1	2.5	3.0	5.6	9.5	8.9
15	15.8	13.9	7.1	4.6	4.8	2.9	2.9	5.9	9.0	8.1
30	6.4	9.1	6.3	4.8	3.2	2.7	2.7	3.8	7.6	6.5
50	5.2	7.9	7.8	5.0	3.5	3.2	3.3	4.2	6.4	6.3
75	3.1	5.1	7.4	5.9	3.5	3.1	3.2	3.2	3.0	4.4
00	3.4	3.2	4.9	5.2	3.3	3.1	3.0	3.2	2.9	3.5
25	3.1	2.8	3.0	3.8	2.8	2.8	2.6	2.7	2.6	2.9
50	2.9	2.5	2.5	3.2	2.3	2.2	2.1	2.4	2.4	2.2
00	2.6	2.2	2.3	2.2	2.1	2.2	2.2	2.6	2.3	2.1
50	2.6	2.6	2.7	2.8	2.5	2.9	2.7	3.3	2.7	2.4
00	3.6	3.7	3.8	3.8	3.5	3.9	3.6	3.9	4.0	4.2
50	7.2	6.9	6.1	6.8	7.2	7.1	6.5	6.9	6.2	6.3
00	8.9	8.1	8.7	7.8	7.9	7.9	7.9	7.7	8.1	7.6

Increase in moisture begins at the depth of 370 to 380 cm. The isopleths with moisture content of 3, 5, and 7% are stable at a depth of 270 to 350 cm. The level of ground waters and its thick (3-meter) capillary margin are also almost stable. In 1955, the change in depth of water table amounted to only 5 cm. All the elements contributing to the rate of change in water table (the summer drop owing to absorption by roots, the autumn rise to make up for it, and so on, as described by Vysotsky, (3)) have but a slight effect on virgin land. The herbaceous plant cover makes use of the moisture available from the upper soil horizons only; the horizons where moisture content comes from precipitation. Moisture from the soil beneath the permanently dry stratum does not enter the plants. The very slight drop in level of ground water is due to seepage common to the entire territory under investigation.

The water balance of the root zone in virgin areas is characterized by a severe lack of moisture. Table 2 gives averages by months for moisture content in the root zone. The moisture

TABLE 2

Change of water content in topsoil (root) layer (1.3 m.) on virgin land, from data for 1946–1950 and 1953–1955

Months	Moisture content	Available moisture	Available moisture
	%		mm.
January	6.8	3.8	72.6*
March	7.0	4.0	76.4
April	6.0	3.0	57.3
May	5.0	2.0	38.2
June	3.1	0.1	1.9
July	2.9	0.0	0.0
August	3.0	0.0	0.0
September	3.8	0.8	15.3
October	5.3	2.3	44.0
November	5.4	2.4	45.9

* Water content calculated by the formula $H = 0.1\ Qhp$, where Q = bulk density, gms/cc; h = thickness of soil layer, cm; p = moisture percentage. 0.1 = conversion coefficient.

available to roots during the spring maximum is only 76.4 mm.

Losses of water during fall-to-winter and early spring periods are due to transpiration and evaporation. They are arranged as follows: March—4.4 mm., April—25.0 mm., May—26.0 mm., June—21.0 mm.; a total of 76.4 mm.

Thus the average monthly water losses from April to June are approximately the same, 21 to 26 mm. In the latter part of June the supplies of soil moisture from spring run low and the grassy plant cover is nourished only by summ precipitation.

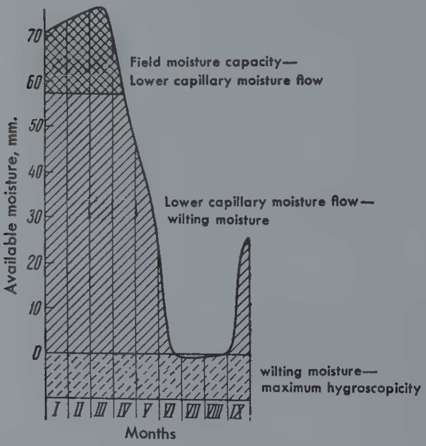

FIG. 2.—Change in water content in the root soil layer in virgin steppe, Bazhigan area, with non-leached type of soil.

It is a fact that the rate of transpiration fine-textured soils drops considerably after tl moisture content in the soil reaches BPK (1, 4 But on coarse-textured soils, as is our case, tl rate of water absorption by plants is not lowere even after the soil moisture content decreas to 6%—the point of lower capillary moistu flow (Fig. 2). The BPK begins April 20th. A the moisture loss from spring storage during Ma and June can be attributed entirely to transpir tion. Its decrease in March by 4.4 mm. is du to evaporation.

In April, two processes of water absorptic go on simultaneously—roots and evaporatio Evaporation from the soil surface protected b plants is not great; we therefore assume that onl one-fifth of the soil moisture content is lost o total evaporation in April (6). Hence the amour of water absorbed by roots during the sprin season is 20 mm. (average for many years).

Spring and especially summertime precipit tion is not of much importance to supplyin

TABLE 3

Water loss (average for many years) on virgin lanc in the Bazhigan area for vegetative season, (non-leached type of soil)

Source of water supply	Months						Total for growth season	% of total los
	April	May	June	July	Aug.	Sept.		
Precipitation								
Spring	20.0	26.0	21.0	—	—	—	67.0	65
Spring and summer	7.0	5.0	5.0	4.8	7.0	6.8	35.6	34
Total	27.0	31.0	26.0	4.8	7.0	6.8	102.6	100
Water loss in 24 hr. period	0.87	1.0	0.87	0.16	0.23	0.23	0.56	

TABLE 4

Water loss for 1954 and 1955, mm. (non-leached typ of soil)

Year	Depth of wetting, cm.	Average moisture content of wetted soil layer, %		Loss of water during growth season, mm.		Amount of precipitation moisture used, mm.	Total transp ration mm.
		Spring	Summer	Total	Transportation		
1954	140	8.7	2.8	121.4	106.5	28.0	132.
1955	60	7.1	2.2	43.2	37.9	52.8	90.

ater to plant because the rainfalls are not fficient. Observations have shown that only ne-fifth of a summer's precipitation moisture n reach to the root systems of the predominatg species of grasses.

The total amount of water absorbed by the ot systems of grasses is 102.6 mm. (Table 3). eviations from average norm for many years re about 30%. Table 4 gives the figures for ater consumption for 1954 which was relatively umid, and 1955 which was dry.

Thus the water use by the plant growing in a on-leached sands of Bazhigan depends entirely n the amount of annual precipitation and mounts to about 90 to 100 mm. The expendiure for transpiration, as determined by the high-peed weighing method at the same hydrological tation also makes up about 100 mm. (2). We an therefore consider our figures close to the ctual amount of water consumed by the plant.

Drought on the virgin steppes in the Terek rea which is made up of the coarser and less bsorbent sands, begins late in May to early in une. By this time, the entire aeration zone with he exception of the capillary fringe has dried ut; the extent of desiccation is from 6 or 8% field moisture capacity) to 2% (wilting moisure). This moisture content remains constant ntil the advent of autumn rains. The total nnual water consumption in areas with a non-ached soil is 110 mm., which is 10 mm. higher han that for the Bazhigan sands. The reason is heavier precipitation, especially in the southern nd western sections of Terek. On the other hand t Tereklin and Kuma where the rainfall is ghter, water consumption through absorption y roots is 80 to 90 mm. In these two areas soil rought sets in during the latter part of May nd continues until September or October; here is more severe than on other areas.

The water regime of virgin meadow-steppe nd meadow areas over leached soils takes on a ifferent pattern. Such areas occur around Terek; ey make the most productive hayfields. Their lant cover gives rich and varied forage. The redominant plants here are: Siberian corn, lue alfalfa, *Agnus castus*, Erianthus and others. he height of the herbaceous stand is 60 to 70 m. Yield from the haymeadows varies between and 10 centner per hectare. Plants such as hite poplar, hawthorn, willow-leaved pear, moke tree, long-leaved juniper, and others grow some localities in the Terek area.

TABLE 5

Soil moisture content of Terek sand area, %
(leached type of soil)

Depth, cm.	1954			1955–		
	March 26	May 19	Aug. 28	Mar. 30	Apr. 26	Oct. 25
5	6.5	3.1	0.9	4.7	5.5	2.0
15	6.4	2.8	0.9	6.3	4.9	0.8
30	6.1	2.6	0.8	5.4	3.6	1.0
50	5.3	2.7	0.8	5.1	4.2	0.9
75	5.6	3.4	0.9	5.2	4.3	0.9
100	5.4	4.7	0.8	0.9	3.1	0.8
125	5.4	5.0	1.6	1.7	1.8	0.9
150	6.3	7.8	1.9	3.9	3.4	1.2
200	8.1	10.3	8.7	9.3	7.2	3.7
250	18.3	—	12.4	—	18.6	10.2
Depth of water table, cm.	256	238	269	247	259	283

A seasonal hydrological station was located on one such area at Sosnovaya Padina survey mark ("Chervlennye Buruny" state farm). The soil here is friable sandy, slightly humus over loose monophase shifting sands. Average bulk density is 1.60 gms./cc. The groundwater table was at a depth of 256 cm. when observations were recorded.

We are using the records of nearby Terekli-Mekteb weather station (located at a distance of 27 km.) for our precipitation data. These were 148 mm., or 42 mm. above average. The average soil moisture in the 0 to 130-cm. layer was 5.7% or 118.6 mm. for March 1954. The capillary fringe is located below this layer (Table 5). By May 19th, the moisture of the 130-cm. layer dropped down to 3.6% or 74.9 mm. of water. The 43.7-mm. decrease in water depth is attributable mostly to absorption by roots and to evaporation. Water seepage into the lower horizons can be practically excluded because the moisture content of the uppermost 130-cm. layer was equal to field moisture capacity as recorded in April. By the end of August, moisture content drops to 0.96% and approaches wilting moisture. The decrease in water content in the year following (1955) did not exceed 0.90%. Loss of water stored in spring between May 19th and August 28th was 54.1 mm.; total evaporation from the 0 to 130-cm. layer was 97.8 mm. throughout the warm season in spring.

If we estimate that 87% of this amount of water is used up by the roots of the plant (the same amount as used by plants growing on

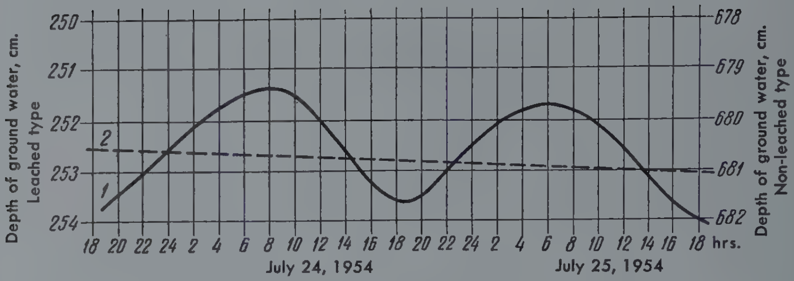

FIG. 3.—Curves for daily changes in ground water table in virgin areas with leached and non-leached type of soil. Terek sands. 1)—Leached type soil; 2)—non-leached type of soil.

Bazhigan sands), we find that the loss of spring storage water was 84.1 mm. at Terek.

The amount of summer precipitation available to plants is estimated at 25 mm. Hence, the total water loss by plants during the vegetative season of 1954 is equal to 109.1 mm. But plants growing on leached soils utilize the ground water in addition to the rain water. The level of these had dropped down to 79.4 mm. of water (16% water discharge) or 31 cm. lower for 1954 (Table 5). This amount of water has been used up entirely by plant roots since there was an absence of percolation during the summer season.

During the summer low in water table level, the daily inflow of ground water is 0.3 mm. The inflowing water comes from the huge sandy hillocks adjacent. The above figure is based on the fact that the water deficiency was made up within 180 days in the course of the fall-to-winter season. Inflow was estimated at 36 mm. during the entire low period (120 days). The allochtonous (8) ground waters are fresh in this instance and cause no perceptible salinization of the soil.

TABLES 6 AND 7

Consumption of water by plants in Terek area for 1954 and 1955 (leached type of soil)

Sources of water loss	1954		1955	
	Amt. of water, mm.	% of total loss	Amt. of water, mm.	% of total loss
Precipitation:				
Spring storage	84.1	37.4	39.5	19.4
Summer addition	25.0	11.1	24.0	11.8
Total	109.1	48.6	63.5	31.2
Ground water:				
Spring storage	79.4	35.4	92.1	45.3
Summer inflow supply	36.0	16.0	48.0	23.5
Total	115.4	51.4	140.1	68.8
Grand total	224.5	100.0	203.6	100.0

The drop in water table level during the summer season is manifested by regular daily fluctuations. Figure 3 gives data for parallel observations on August water tables of sections with leached and non-leached types of soil. The underground water is utilized by the plant cover in the first case but not in the second case.

The daily fluctuations in water table level are of great practical interest because they make it possible to determine whether or not a certain phytocenosis is using up the underground water or whether the gradual drop in water table is due to drainage.

A characteristic feature of plants with leached type of soil regime is that more than half of the water absorbed by their roots is underground water (Table 6). The chief consumers of ground water in the Terek area (when the water table is less than three to four meters below ground) are the blue alfalfa and in part the Agnus cactus, in which the root systems are well developed and penetrate deeply.

During the fall-into-winter season of 1954–1955, the precipitation was 106 mm., or 50 mm. less than during the winter preceding. This decrease in amount of precipitation was responsible for the decrease in wetting depth. While in the winter of 1953–54 precipitation had reached only the capillary fringe, in the following year the wetting was only 90 cm. deep, so that there was only a small non-wetted stratum left in the aeration zone. During the 1955 vegetative season, the moisture content of the wetted layer dropped down to 0.9%, and the water table was lowered by 36 cm. (Table 5). Total water losses in transpiration are given in Table 7.

In spite of the difference in moisture content or the two years, the figures for amounts of vater used up by roots are similar. The deficiency n atmospheric precipitation was compensated y underground water. As a result, there was a reater drop in water table, and consequently, more rapid inflow from the adjacent areas.

Thus the herbaceous plant which, like the voody plants, depends on the water table for ts supply of water, compensates for the lack in noisture by making use of the water table. In his way it is possible to produce constant and airly high yields of hay in localities with a eached type of soil.

Conclusions

1. The virgin areas between Terek and Kuma ivers vary from leached to non-leached types f soil; the non-leached type predominates.

2. The amount of H_2O consumed by the roots f steppe vegetation on non-leached silty sands nd sandy loams depends on the amount of recipitation and equals 90 to 110 mm.

3. The amount of water consumed by plants rowing on leached soils of the same texture is ut slightly dependent on the amount of precipiation; it amounts to 200 to 220 mm. A lack of ainwater is compensated by groundwater; the atter is taken up by the roots. The result is a egular daily and seasonal fluctuation in the vater table. In such areas more moisture is lissipated by evaporation than added by preipitation.

4. The specific makeup of the ground cover hould include plants whose root systems spread ver the soil surface as well as those whose roots enetrate deeper into the ground. This will peed up moisture absorption. The ground cover should be as dense as possible in order to reduce evaporation of water from the soil.

5. Depressions that have a leached type of soil should be leveled out and included in crop rotation programs. A network of windbreaks should be also grown for this purpose.

6. When the Terek-Kuma canal and its sandy tributaries are introduced into action, the water table will rise and the number of areas with a leached type of soil will increase. The consequence of this is new possibilities of higher and more constant yields of hay.

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EFFECT OF PARENT MATERIALS ON THE EROSIVE ACTIO ON THE RIGHT BANK OF THE OKA RIVER[1]

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THE parent material of the eroded and non-eroded dark-gray forest soils on the right bank of the Oka River in Moscow region consists of two layers of different textures. This two-member parent formation is widely distributed throughout the European portion of the Soviet Union. It is of fluvial-glacial origin and the upper and lower layers vary in thickness and texture.

Publications by Vysotsky (1, 2) and Lebedev (3) have shown that soils formed on a two-member formation have specific water and chemical characteristics. Moreover, the moisture capacity of soils developed on non-homogeneous parent materials varies depending on the disposition of fine- and coarse-textured layers. Rode (6) notes that when soils are stratified in such a way that a highly-porous layer occurs above a low-porosity impermeable layer, the upper layer becomes a temporary horizon for water percolation when excessive moisture (melt water or flask flood run-off) occurs.

A characteristic feature of soil profiles of this type is the presence of a lighter horizon at the point of contact between layers of varying textures (1, 2). When the upper layer has greater porosity (or has coarser texture) than the layer beneath it (finer texture), periodic moisture saturation along the contact between the layers will institute a gleying process without significant accumulation of ferrous oxide (7).

When the upper, finer texture layer is underlain by coarse textured soils, a new water regime and chemical properties of the soil profile are created. In this paper we shall investigate the moisture properties of the dark-gray forest soils in various eroded stages as they are related to the nature of the parent material formations.

The upper, fine-textured cover of loess-like clay loam is about two meters thick. It should be noted that deposits of the specified thickness are observed on watersheds (Profiles No. 55, 61) and slopes of varying steepness and exposure (Profile No. 51, 54, 57). Dark-gray non-eroded fores soils are developed on the watersheds at an ab solute elevation of 190 to 200 meters. Slightly o medium-eroded dark-gray forest soils originatin from the same two-member formation occur i the middle and lower portions of slopes havin eastern or western exposures at absolute elevations between 180 and 155 meters.

Results of particle size analysis (Table 1) indicate that the predominant elements in paren material are clay and coarse silt. The clay content in the upper part of the deposit exceeds tha of the coarse silt. The percentage of these particles in the upper layer (180 to 200 cm.) varies within very narrow limits under various relie conditions. The clay is 40 to 41% and the coarse silt, 33 to 35%. In the parent material below the contact, the percentage of coarse silt is higher than that for clay. The content of the first is 51 to 59%; the second, 23 to 30%. Thus the two layers of the deposit differ greatly in clay and coarse silt content. The clay content of the upper layer is 10 to 17% higher than that of the parent formation. The varying textures of the parent material determine differences in porosity of the layers, and are responsible for the specific conditions of water regime in the soil profile. To be sure, such changes in the soil textures are difficult to detect and can be determined only by analytical methods.

Lebedev (3) wrote, ". . . A humus and concentrated sesquioxide horizon must develop along the contact between the upper layer of fine earth parent material and its coarser-textured equivalent. Somewhat farther down in the lower portion of the fine earth layer and in the upper portion of the coarser-textured material adjacent to it, there is a carbonate horizon" (page 175). These considerations of Lebedev's have been confirmed by our data on the humus and carbonate content of dark-gray forest soils developed on the two-member parent material (Table 2).

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[1] Work performed under the direction of S. S. Sobolev on the semi-permanent soil-erosion studies of collective farms by the Nineteenth Party Congress of the Kashir District of Moscow region.

TABLE 1

Particle size analysis of parent materials (at the contact between two of its layers) in eroded and non-eroded, dark-gray forest soils in Moscow Region (analyzed by the pipette method of N. A. Kachinsky; A. P. Kulakova, analyst)

ro-file No.	Soil, land type, slope, exposure, elevation	Depths, cm.	Hygroscopic moisture, %	Solution losses with HCl, %	Diamter of particles, mm.					Clay <0.001	Physical clay
					Sand		Silt				
					Coarse	Fine	Coarse	Medium	Fine		
					1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001		
51	Medium-eroded, dark-gray forest soil. Plowed field. 5°, North-East, 155 m.	180–185	6.18	1.69	0.17	None	32.76	10.93	13.77	40.68	65.38
		290–300	3.01	1.19	0.07	2.25	59.29	8.07	5.98	23.15	37.20
54	Medium-eroded, dark-gray forest soil. Plowed field, 3°, E-N-E, 185 m.	180–190	4.05	2.07	0.65	1.98	33.71	10.19	9.57	41.83	61.59
		220–230	3.41	9.56	0.14	1.37	50.88	7.52	5.50	25.03	38.05
55	Non-eroded, dark-gray forest soil. Plowed field. Watershed, 1°, W-S-W, 190 m.	180–190	6.09	1.79	0.38	None	33.84	11.67	12.01	40.30	63.98
		220–230	3.38	1.71	0.04	0.41	56.28	9.72	5.91	25.93	41.56
57	Slightly eroded, dark-gray forest soil. Plowed field. 3.5°, W-S-W, 180 m.	195–200	3.13	4.78	0.39	None	35.39	10.19	11.14	40.01	61.34
		200–210	4.54	10.10	0.41	”	41.28	7.64	10.45	30.22	48.21
		210–220	3.64	5.81	0.37	”	44.78	8.10	10.14	30.90	49.19
		220–230	3.09	2.80	0.13	”	51.54	9.48	7.02	30.30	46.80

The humus content of the eroded and non- oded arable layer varies from 2.28% to 2.89%. resnyakova (4) obtained similar values for the umus of the arable horizons of the forest soils in arious eroded stages. However, the humus hori- on in the eroded soils is much thinner than in e non-eroded. For example, in the non-eroded ark-gray forest soils, the thickness of the hori- on having a 1% humus content is approximately 2 to 54 cm., but is no more than 25 to 30 cm. hen the amount of erosion is normal. Hence, follows that the erosion of the upper soil layers only about 20 to 30 cm. The amount of humus uniformly distributed throughout the soil pro- le from the lower limits of the humus horizon + B) to contact with the layers of the parent aterial. Below this contact where the materials e of various textures, the amount of humus ecreases abruptly. If the humus content of the yer above the contact is 0.5%, lower down it is 34% (Profile No. 61), or 0.49% and 0.19% rofile No. 55) and 0.58% and 0.28% (Profile o. 51), respectively. This distribution of humus long the contact line of two parent materials of arying texture has been observed in both eroded nd non-eroded dark-gray forest soils.

Observations on the distribution of root systems (mostly Equisetum) in the soil profile have shown that roots occur from the surface soils to the parent material contact. They do not appear below the contact in the coarser-textured layers.

Maximum carbonate content is observed in the dark-gray forest soils along the contact between the two types of parent materials; that is, in the the lower portion of the fine-textured upper layer and in the upper portion of the coarser-textured parent material. This is apparent from CO_2 determinations (Table 2) and indirectly from the amount of solution loss in pre-treatment of the soil with HCl (see Table 1). Thus, for example, the CO_2 in the non-eroded dark-gray forest soils above the contact (190–200 cm.) was 0.13% and in the lower layer (210 to 220 cm.) it increased to 1.54%. However, this distribution type of carbonate does not always occur in soils of varying textures. For instance, the CO_2 content of the dark-gray, highly-podzolized forest soils (with traces of silica to 150 cm. See Profile No. 55) varied between 0.01% and 0.04% throughout the profile.

Reduced data indicate the peculiar process of soil formation resulting from a diversity of textures in the parent material.

Of special interest in the given data is the water

TABLE 2

Humus (after Tyurin) and carbonate content (after Golubev) in the dark-gray forest soils produced on two-layer parent material
Analysts: E. M. Rosenblum, K. I. Vassil'yeva (humus), A. P. Kulakova (CO_2)

Non-eroded soil. Watershed. Absolute elevation 200 m. Profile no. 61			Non-eroded soil. Watershed Absol. elev., 190 m. Profile no. 55			Medium-eroded soil. Slope, 3°, E-N-E. Absolute elev. 185 m. Profile no. 54			Medium-eroded soil Slope, 5°, E-N-E. Ab lute elevation 155 m Profile no. 51	
Depth, cm.	Humus, %	CO_2, %	Depth, cm.	Humus, %	CO_2, %	Depth, cm.	Humus, %	CO_2, %	Depth, cm.	Humus,
0–5	2.89	None	0–5	2.28	0.04	0–5	2.31	—	0–5	2.41
15–20	2.82	”								
25–30	2.60	”	17–23	2.31	—	15–20	2.34	0.02	10–15	2.72
30–45	1.88	”	27–32	1.45	—	25–30	1.51	—	20–25	0.99
40–45	1.46	0.03	40–45	1.17	0.03	35–40	0.82	—	30–35	0.58
49–54	1.43									
65–70	0.71	None	47–52	0.97		40–50	—	0.01	45–50	0.50
80–85	0.45									
95–100	0.36	0.01	60–65	0.61	—	90–100	—	0.01	70–75	0.45
120–125	0.25									
150–160	0.13	0.02	71–76	0.49	0.02	140–150	—	0.02	90–95	0.46
170–180	0.20	—	85–90	0.54	0.04	200–210	—	0.38	100–115	0.41
190–200	0.19	0.13	110–115	0.39	—	210–220	—	1.32	125–130	0.45
210–220	0.41	1.54	125–130	0.43	—	220–230	—	0.8	150–155	0.45
220–223	0.55	1.98	145–150	0.41	0.03	230–240	—	0.03	180–185	0.58
230–240	0.34	1.32	175–180	0.51	0.03	240–250	—	0.02	290–300	0.23
240–250	0.13	3.82	180–190	0.49	—	270–280	—	0.01	470–480	0.19
260–270	0.05	2.05	210–220	0.19	—	300–310	—	0.02		
280–290	—	3.30	240–250	—	0.01	320–330	—	0.01		
300–310	—	3.52	290–300	—	0.01					

regime of the dark-gray forest soils in varying stages of erosion. The distribution of moisture along the soil profiles developed on the two-member parent material is given in Figure 1. The graphs show a marked change in moisture content of soils planted to agricultural crops (b, c) throughout the growing season as observed in the upper horizons of the soil profile. The common characteristic of the moisture content curves indicates that the amount of soil moisture increases toward the contact between the layers, reaching a maximum above the contact. The moisture content of the soil layer above the contact varies in this case from 29% to 31% to 32% (in weight of soil). This amount of moisture exceeds the corresponding minimum moisture content by approximately 10%.

It should be noted that this distribution of moisture in the soil profile does not depend on relief of the locality, on its exposure, steepness of slope and degree of soil erosion, but is a specific characteristic of the heterogenous parent material.

In order to emphasize the specific character of the water regime in soils developed on two-member deposits, data characterizing the distribution of moisture in common chernozems originating from uniform, highly fine clay loam parent materials in Altay County are provided. Figure 2b gives the curves for the distribution of clay fractions, soil moisture content during the summer season, and the moisture content corresponding to the minimum moisture capacity (in percent of soil weight). It is obvious that the soil profile data are characterized by uniform texture. The curves of the dynamics of soil moisture indicate that the change in soil moisture occurs only in the upper 50 cm. layer (July 25–Aug. 5). Deeper in the uniform soils it varies as much as 14% to 16%.

The foregoing data show how very important the stratification of parent materials is to the water regime of soils.

It is recognized that Lebedev (3) developed the theoretical work on problems concerning the water characteristics of stratified soils. Investigating the water regime of uniform and heterogeneous soils he wrote, "at the contact between the fine-textured layers above and the coarse-textured layer below, conditions are present for the formation in the fine-textured layer of *suspended capillary* water" and again, "the moisture of the fine-textured layer above a coarse-textured layer at the moment of equilibrium *will be greater* than when the fine-textured parent material was de

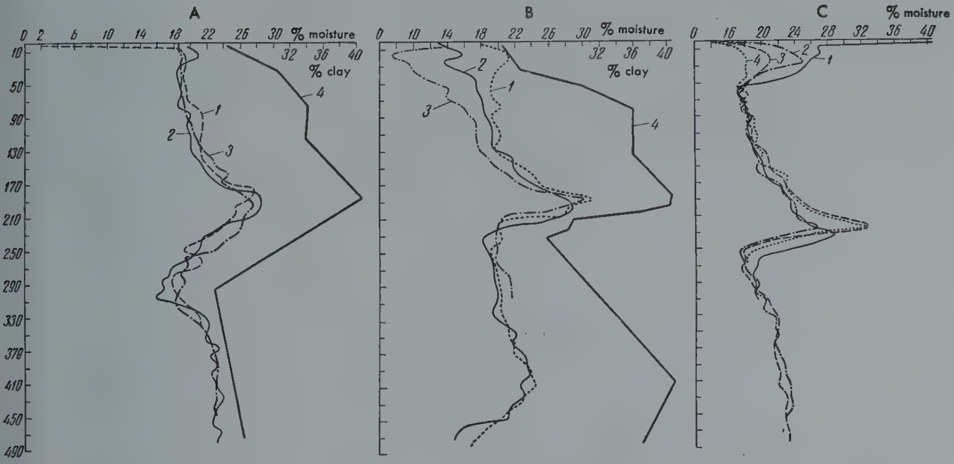

FIG. 1.—Soil Moisture Curves, occurring in a two-member, parent material (% soil weight).

a. Medium-eroded, dark-gray forest soils. Profile No. 51, lower portion sloping 5° E-NE in black fallow, 1956. 1—June 6; 2—June 27; 3—August 10, 1956; 4—% of clay.

b. Noneroded dark-gray forest soils. Profile No. 55, 1° run-off, W-SW. Planted to corn in 1956. Spring Wheat Crop in 1957. 1—July 19, 1956; 2—August 2-16, 1956; 3—August 2, 1957; 4—% of clay.

c. Noneroded dark-gray forest soils. Profile No. 61, run-off 0.5° S; planted to corn in 1957. 1—April 10; 2—April 28; 3—August 3, 1957; 4—August 3, 1957.

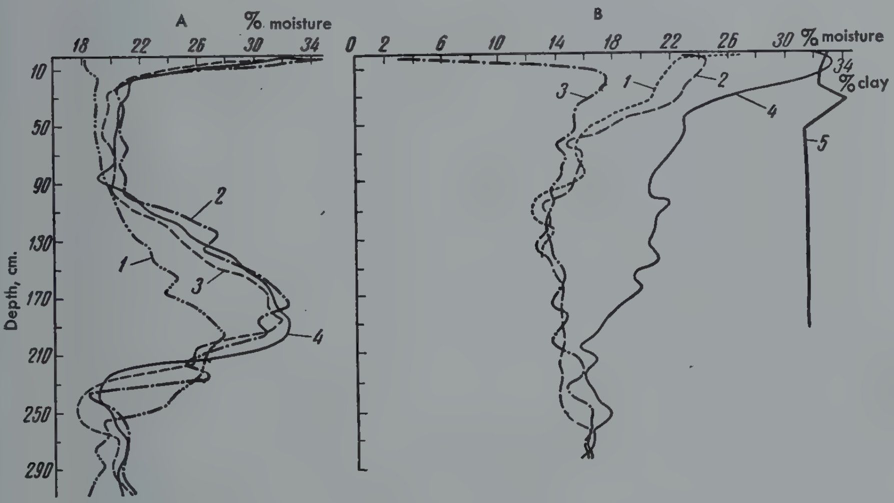

FIG. 2.—Soil Moisture Curves After Floods (% of soil weight)

a. Medium eroded, dark-gray, fine clayloam forest soils, developed on a two-member parent material. Profile No. 51, Moscow Region. 1—Initial; 2—After 3 days; 3—After 7 days; 4—After 15 days.

b. Normal, fine clayloam chernozems, developed on a uniformly textured parent material Profile No. 1, Altay County. 1—June 25; 2—July 15; 3—August 5, 1955; 4—NV (Minimum water capacity; 5—% of clay.

posited as a uniform, continous mass" (page 154). Rode (6) developing this thesis wrote that the soil moisture above the contact between two layers (fine-texture above and coarse-texture below) exceeds the amount of moisture corresponding to the minimum moisture capacity and calls it the free moisture capillarity under suspension (page 65).

The foregoing data indicate that Lebedev's experiments investigating moisture in homogeneous soils and those stratified according to texture are in complete agreement with conditions observed in nature. The presence of free capillary ground water in soils is of the utmost importance to agriculture. A. A. Rode stated: "Free capillary ground water in this case, as well as naturally free moisture, possesses great mobility and is exceedingly available to vegetation" (page 65).

The presence of free capillary-ground water in soils, because it comes to the surface daily, plays another important role in the study of water erosion and its control. It should be noted that in attempting to control soil erosion in fields this increase in moisture must be anticipated. Sobolev (8) wrote that "in erosion control—the front line is the protection and accumulation of soil moisture" . . . (page 388). He suggested a system for moisture improvement by which moisture supply in soils would be increased (9). However, in order to accomplish this, soil and hydrogeological conditions must be considered.

Our investigations have demonstrated that in soils developed on homogeneously- and heterogeneously-textured parent materials, after the upper portions of the soils have been supersaturated, moisture distribution along the profile varied considerably (Fig. 2a).

After the upper portion of soils developed on homogeneously textured parent materials have been saturated, the moisture content reaches equilibrium, gradually diminishing with depth (Fig. 2b). The thickness of the soil layer where moisture equilibrium corresponded to minimum water capacity, (21% to 22%, soil weight) was 150 cm. In the 150 to 230 cm. layer, soil moisture was less than water capacity and still deeper (230 to 300 cm.) wetting was not observed. Under these conditions, by increasing the water supply above, the depth of soil saturation is increased. When it approaches equilibrium the moisture content of the layer will not exceed the value for minimum water capacity. In homogeneous soils, supplementary wetting of upper soils will help to increase the thickness of the soil lay in which moisture corresponds to the minimu water capacity. Conditions for development free capillary moisture in suspension are not pre ent here.

The picture is very different for soils develope on a two-member, parent material. Figure 2 shows the curves characteristic of free, suspende capillary moisture which develop after the moi ture of the upper portion of the soils has bee increased. Here, where the parent materials ar not of uniform texture, the amount of soil mois ture exceeds the value of minimum soil capacit and does not increase with depth as was observe in homogeneous soils. On the contrary, it increases with proximity to the contact betwee the two parent materials. Maximum moistur content is between 30% and 32% (or about 88% of total moisture capacity) as observed above th contact between layers of different texture Moisture in the underlying layer (the finer textured) diminishes sharply to 18%. Therefore when there is excessive wetting in the upper soil the amount of moisture in the layer between the contact and the diurnal surface will be increased exceeding the amount of moisture corresponding to minimum moisture capacity. Under these conditions wetting will cause saturation in the upper soil layer and, when erosion takes place, contribute to wash-outs and landslides. Here, agrotechnological measures must be developed to prevent erosion processes contributing to excessive water but still not accumulate too much on the surface. It is possible to control excessive water by laying out grass waterways with drains at the ends.

When free capillary moisture in suspension is present in areas of indefinite relief and when precipitation is abundant, it is possible to anticipate temporary inundation. The soils of the Leya-Bureinsk plain are an example of such a condition. Pustovoytov's data (5) of characteristic texture and soil moisture make it obvious that the upper layer of fine texture had a thickness of approximately two meters and was underlain by sandy deposits. The clay content of the upper layer of the formation was approximately 40% and that of coarse silt about 30%. There was no clay in the underlying layer and the silt did not exceed 6%. The amount of moisture in the layer above the contact was about 25% to 30% and below the contact, between 7% and 10% (in soil weight). Data indicate the presence of free capillary moisture in suspension in the soils of the Amur region.

der monsoon-like conditions, the soils are
atly over-saturated, hampering agricultural
oduction (soil cultivation, crop harvesting).

Conclusions

1. The dark gray, forest soils of Moscow Re-
n formed on covering loess-like clay loams
ich are independent of relief, are approximately
o meters deep and underlie coarser-textured
posits. In the upper layer, at the contact be-
een the two parent materials, the clay content
between 10% and 17% greater than in the
derlying formations.

2. The two-member, parent material in the
vestigated area contains soils having specific
ter and chemical characteristics.

When there is an upper, fine-textured layer and
underlying coarse-textured layer, conditions
e favorable for the accumulation of free sus-
nded capillary moisture above their contact.
e amount of suspended capillary moisture
ove the contact varies between 37% and 32%
soil weight) independently of relief, exposure,
epness of slope and stage of soil erosion.

3. Where free capillary moisture under sus-
nsion is present, supplementary wetting of the
per layer can supersaturate the upper horizon
d thus further soil erosion.

4. In soils developed on parent materials of
mogeneous texture, free suspended capillary
isture does not develop. Wetting these soils
preventive erosion practices taken under
ese conditions may have the utmost production
nificance. In soils formed on a two-member,
rent material, where the moisture is adequate
d the layer contact is close to the diurnal surface, it is necessary to utilize erosion control practices to control water erosion.

Methods of procedures may be: soil cover crop rotation on plowed slopes with a higher percentage of fields planted to perennial grasses and perennial grass strips—buffers, combined with plowed furrows.

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A METHOD FOR CHEMICAL ANALYSIS OF ROOTS[1]

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IMPROVED methods of separating roots from impurities—soil particles—were needed to study the role of roots in the cycle of mineral elements in grasses.

In handbooks on agricultural chemical analysis, Dem'yanov and Pryanishnikov (3), Shestakov (4), and others recommend washing the roots with water, drying, and analyzing. It is not always possible to wash soil completely out of roots. When the root sample is taken from moist, coarse textured soil it is easier; with dry clay soils, it is more difficult.

Root weight is determined exactly by ashing, determining the amount of contaminants in the ash, and subtracting it from the weight of roots.

The determination of mineral elements in roots is much more complicated, since acid treatment of the ash dissolves some of the contaminating elements together with those in the root ash.

There is at present no completely satisfactory method for removing soil from roots, and analyses of root ash are therefore somewhat unreliable. The most complete descriptions of the preparation of plant materials (lichens and mosses) for analysis are given by Aleksandrova (1) and Bobritskaya (2).

L. N. Aleksandrova suggested removing mineral contaminants from soil by mechanical separation and chemical treatment of the ash. Mineral particles are separated from plant material, first, by picking out under a magnifying glass, and second, by elutriation with water or ether. Since water dissolves part of the elements in plant material, it is recommended that the elements in solution be determined and the amounts added to the analyses of plant ash.

Use of the foregoing method does not give complete separation of mineral particles fr plant material. Therefore, dissolving the ash 5% HCl after preliminary mechanical separati and ashing is recommended in the handboo It is assumed that the acid does not dissolve t determined elements from the mineral parts the soil, but does dissolve all of the elements plant ash, except SiO_2. Silica dissolves from t residue left after treatment with 5% HCl, up treating it with 5% KOH.

Somewhat later, M. A. Bobritskaya us Aleksandrova's method for preparing differe samples for analysis. Under a binocular micr scope, she mechanically removed mineral co taminants from stalked and rosette lichens aft which the rosette form was washed two or thr times with ether. In one trial, lichens were groun to 0.25 mm. pieces with a wooden pestle in a agate mortar, then centrifuged at 10,000 rp with bromoform (sp. gr. 1.8) and washed wit xylol.

She prepared mosses for analysis differentl Fine soil particles at the base of the moss we removed with tweezers. The moss was the washed with distilled water, dried, and observe under a binocular microscope. In the author opinion, neither method of cleaning was com pletely satisfactory.

We propose a method for root analysis whic avoids the effect of the solvent action of the solu tion used to wash the soil from the roots. Thi method is based on the assumption that a so sample taken for analysis, and one adhering t the roots, are identical.

The method consists of paired analyses of roo and soil which have been mechanically separate from the roots. The roots and soil are ashed an treated with HCl (it is possible to treat the as with concentrated HCl and HNO_3), and as de scribed by L. N. Aleksandrova, the insolub residue is treated with 5% KOH to dissolv amorphous silica.

The difficultly soluble mineral part of the so (referred to below as the "mineral part of the soil" is ignited, weighed, and its percentage calculate From this percentage and the weight of miner contamination in the root sample, the amount

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[1] A method of root analysis is described in articles by R. Kh. Aydinyan (Pochvovedeniye, No. 9, 1953, and No. 1, 1954), which the present author did not draw upon. The method suggested in those articles is very difficult, and may be recommended in cases where the separation of mineral contamination from roots presents greatest difficulty, for example, for the analysis of very fine roots, roots of halophytes, which cannot be washed with water, thalli of crust lichens, etc.—Editor.

l in the root sample taken for analysis is de-
rmined. The weight of the soil is subtracted
m the original weight of the roots to give the
ight of clean roots. The content of all deter-
ned elements in roots is found from the soil
d root analyses. The amount belonging to the
l is subtracted from the total content in the
t sample, and the percentage in roots is cal-
lated from the difference.

The analytical procedure is as follows. The
t sample is taken from a meadow or field to a
own depth of the soil profile, or from plowed
lds to plow layer depth. It is then separated
m most of the soil, air-dried, and packed for
ipment to the laboratory. The roots are care-
lly cleaned from adhering soil particles and
ound according to the analysis to be carried
t: coarse crushing may be enough for dry ash-
; finer grinding is necessary for wet ashing.
il taken from the roots is placed on tracing
per and the root pieces are carefully picked
th tweezers. The pieces are added to the main
ss of roots. Separate weights of roots with the
l adhering to them and soil without roots are
n placed in large weighed porcelain crucibles
dishes. The crucibles with roots and soil are
ied to constant weight in an oven at 100–105°C. The percent of hygroscopic moisture may be determined from the loss in weight. The roots are then ashed and the soil ignited at a temperature not exceeding 450–500°C., as recommended in many handbooks on ash analysis.

The residue is transferred from the crucible to a beaker and moistened with a few drops of water. Then 50 ml. of 5% HCl is added and boiled for a few minutes. The insoluble soil particles and silica are filtered out and washed with dilute HCl until Fe and Ca are not present in the washings. The filtrate is transferred to a large porcelain dish, evaporated, and the dry residue is treated three times with aqua regia and several times with concentrated HCl in order to dehydrate and precipitate silica. Silica is filtered off (The filtrate is caught in a volumetric flask.), washed, and the filter is placed in a previously ignited and weighed crucible, ignited, and weighed. The percentage of silica in the soil and roots is calculated.

The Fe, Al, Mn, Ca, and Mg are determined in the filtrate. The mineral part of the soil, remaining after treatment with HCl, is transferred to a beaker. Then 50 ml. of 5% KOH is added and boiled 20 minutes, as indicated by L. N. Aleksandrova. The mineral part of the soil is filtered from the alkali soluble silica and washed with

TABLE 1

Computation sheet for composition of mineral part of soil and chemical elements in roots

mple description and number, depth, cm.	Weight, gm.	Mineral part of soil		Ca			Mg			Mn	
		Weight, gm.	%	ml. $KMnO_4$ 0.0573 *N*	×1.146 (0.0573 × 20) in mg.	%	Weight $Mg_2P_2O_7$, gm.	×0.2185 (gravimetric factor) gm.	%	Mn in sample, mg.	%
Soil, 0–10	5.1552	3.8076	73.86	16.0	18.336	0.35	0.0855	0.018682	0.36	3.26	0.063
Roots, 0–10	9.0962	2.1712		54.5	62.457		0.1055	0.023052		4.280	
il) S	−2.9396				−10.290			−0.010582		−1.852	
oots) R	6.1566				52.167	0.85		0.012470	0.20	2.428	0.039

der of computation:

Determine percentage of mineral part of soil: 1) weight of soil on the roots $= \frac{2.1712 \times 100}{73.86} = 2.9396$;
weight of clean roots $= 9.0962 - 2.9396 = 6.1566$ gm.
Computation of Ca: a) 100 gm. soil contains 350 mg. Ca, amount of Ca in 2.9396 gm. soil $=$
$\frac{396 \times 350}{100} = 10.29$ mg.; b) amount of Ca in roots $= 62.457 - 10.290 = 52.167$; 3) percent Ca in
ts $= \frac{52.167 \times 100}{6.1566 \times 1000} = 0.85$.
Computation of Mg: a) amount of Mg in 2.9396 g. soil $= \frac{2.9396 \times 0.36}{100} = 0.010582$ gm.; b) amount of
in roots $= 0.023052 - 0.010582 = 0.01247$ gm.; c) percent Mg in roots $= \frac{0.01247 \times 100}{6.1566} = 0.20$.
Computation of other elements is carried out in the same manner.

TABLE 2

Content of mineral elements in soil and roots of grassland vegetation in percent of dry weight (100–105°)

(Analyses: L. N. Bykova and A. P. Mzhel'skaya)

Sample description	Depth, cm.	Weight, gm.	Mineral part of soil, %	Si	Fe	Al	Mn	Ca	Mg	K	Na	P
Soil	0–5	6.5563	78.19	2.22	1.46	1.21	0.04	0.16	0.23			0.13
"	"	5.6154	78.24	2.36	1.42	1.21	0.04	0.14	0.26			0.12
Roots		2.4628		2.43	0.50	0.73	0.05	0.39	0.17			0.21
Soil	0–5	7.0962	74.38	2.30	1.97	1.35	0.05	0.32	0.29	1.15	0.45	0.09
"	"	6.4187	74.20	2.32	1.92	1.41	0.06	0.33	0.30		0.49	0.09
"	"	5.8095	74.38	2.54	1.96	1.08	0.06	0.33	0.23			
Roots		3.2230		2.49	0.79	0.36	0.02	0.38	0.27	2.73	0.87	0.23
"		2.4910		2.00	0.74		0.02	0.40	0.24			0.22
Dry grass		3.8674		2.72	0.32		0.02	0.31	0.22			0.21
" "		4.0048		2.45	0.36		0.02	0.31	0.24			0.21
Soil	0–10	6.4822	49.81	4.75	3.74	1.56	0.01	0.68	0.44		0.082	0.057
"	"	5.1290	49.35	4.91	3.77	1.35	0.01	0.66	0.35		0.103	0.09
Roots	0–10	4.9636		1.78	0.36	0.16	0.01	0.87	0.38		0.074	0.29
Soil	0–10	6.2002	79.59	1.94	1.80	0.72	0.04	0.35	0.26	0.22	0.0003	0.105
"	"	6.8987	79.00	2.24	1.77	0.62	0.04	0.37	0.27			0.11
Roots	0–10	5.5064		1.67	0.79	0.23	0.03	1.19	0.29	0.69	0.09	0.20
Soil	0–10	5.1552	73.94	2.55	2.27	1.05	0.06	0.36	0.36	0.25	0.035	0.035
"	"	4.3017	73.78	2.71	2.22	0.95	0.06	0.34	0.32			0.17.
Roots	0–10	6.1562		2.50	0.93	0.42	0.04	0.85	0.21	0.68	0.134	0.20
"	"	3.9265		2.62	1.36			0.89	0.27			

neutral 2% NH_4NO_3 until no alkali remains in the washings. The filtrate is evaporated and silica determined. The mineral part of the soil is transferred to a weighed crucible, ignited, and weighed.

Examples are given in Table 1. We performed all calculations on the elemental basis and did not consider it necessary to determine oxides.

The data obtained with the method of paired analyses of roots and soil gave a favorable evaluation of the proposed method. Roots and soil were taken for analysis from grassy vegetation and stubble residues from the Klyaz'ma River flood plain in the region of the Chashnik agrobiological station of Moscow State University. The data in Table 2 show that: the percentage of the mineral part of the soil is constant in replicate determinations; iron and aluminum contents are considerably less in roots than in soil; calcium, potassium, and phosphorus contents are greater in roots than in soil; magnesium contents are almost the same in roots and soil; silica contents show little difference in roots and soil.

The proposed method can be used to determine total nitrogen in roots. The nitrogen determinations are carried out by the usual Kjeldahl method. The amount of soil on roots, expressed in grams, must be converted to percent to calculate the nitrogen content of roots. For example in a root sample weighing 9.1 gm., 2.912 gm. o soil was found, which amounts to 32%. If a 0. gm. root sample were taken for nitrogen determination, there would be 0.16 gm. soil and 0.3 gm. roots. The amount of nitrogen in 0.16 gm soil is determined and subtracted from the tota content of nitrogen in the root sample (0.5 gm.) The percentage of nitrogen in the roots is calculated from the remaining amount of nitrogen an the weight of 0.34 gm. The method may also b used for determination of micronutrients in roots

Conclusions

A proposed method of paired analyses of root and soil differs from earlier methods of removin roots from soil in that it avoids the solvent effec of any solution used for washing soil from roots The analyses may be carried out with either dr or wet ashing. Extraction of mineral element from ash may be accomplished with concentrate acids. The method is also used to determine tota nitrogen content of roots.

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MODIFICATION OF THE BP-44 AUGER FOR USE ON COMPACTED SOILS

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OWING to the extension of steppe afforestation there is an increasing need for soil-moisture control on forest plantations, whether established recently or some time ago, in the forest belts. The lack of a reliable auger is a serious drawback in this work. The present mass-produced soil auger is quite inadequate. Its primary feature is the cutting part of the auger head, in which there are no teeth for cutting out the soil. It was evidently designed to plunge into the soil and slide down into it with a spiral movement caused by the spiral-shaped cutting-edge of the barrel. The soil core about to enter the auger must be cut out by the whole of the end of the auger, the extremities of which are sharpened, the edge running towards the inner part of the barrel.

Numerous field tests with the BP–44 revealed the faults in its construction. It was found to be suitable only for soils of friable structure, for instance chernozems, on which, generally–speaking, augers of any type are suitable. On compacted, excessively dry soils, which occur as a rule in the south and southeast of the European part of the Union and in central Asia, the auger was found to be unsuitable. Soils of the steppe and semi-desert zones covered by tree plantations are particularly difficult to sample. The soil is intensively dried to a depth of 3 to 5 m. by various tree species. Dry clay loams and clays are extremely compact from 25 to 30 cm. down, even if soft at the surface, and this prevents the insertion of the BP–44 auger. With this in mind we modified the BP–44 auger for use on compacted soils.

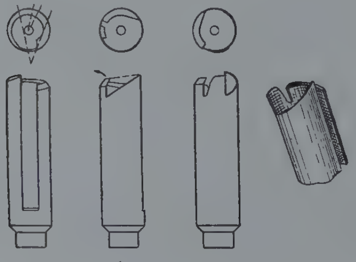

FIG. 1.—Modification of the barrel of the BP–44 auger. *a*—General view of the barrel; *b*—after cutting two parts of the cutting edge; *c*—after turning out a second and third tooth; *d*—general view after modification.

The essential features of our modification are shown in the figure (*b*, *c*, and *d*). Two pieces are sawed out of the fore-end of the barrel with a hacksaw, the temper of the auger having been drawn beforehand. First of all three cuts are made to a depth of 1.5 cm. in the directions indicated by the lines in the upper part of figure *a*. At the same time an angular cut is made in the broad part of the bevelled edge of the barrel. After this a piece of the barrel is sawed out along a line running from the front (cutting) end to the base of the first saw cut. Three teeth are formed at the end of the barrel (figure *b*). Then the barrel is brought up to red heat and the end of the second tooth is carefully straightened by tapping it lightly, and the whole tooth turned 1 to 1.5 mm. further out from the auger's axis than the first tooth, which is not turned out and is of one piece with the remaining, cylindrical part of the barrel. In the same way a third tooth is turned outwards 1 to 1.5 mm. further than the second tooth (figure *c*). The barrel is hardened.

The value of the second tooth lies in the fact that, for boring hard soils, a tooth should not be turned out too far because it hampers boring and also is subject to rapid wear or turns out further and so ruins the auger, particularly if the soil is frozen through.

The general view of the cutting part of the auger is given in figure *d*. The cutting part of this model is similar to the old Izmail'sky auger. The difference consists in introducing an additional tooth and turning the teeth outwards, which gives a bore considerably wider (4 to 6 mm.) than the external diameter of the barrel and completely eliminates friction of the auger against the wall of the bore. Owing to the considerable thickness of the walls of the BP 44 auger's cylinder (about 2.5 mm.), to the good quality of the steel, and also to the set of the teeth, no contraction of the auger in the bore hole is observed.

Boring with the auger is done as follows. As the auger is turned, the first and longest tooth (the teeth differ in length by 2 to 3 mm.) makes a ring–shaped cut. The second tooth, following the first, widens the cut by easily removing a slice 1 to 1.5 mm. thick. The third tooth widens the cut by a further 1 to 1.5 mm. so that a core is cut out and enters the auger. The resistance of the soil to the boring is negligible.

Augers of the type described have been tested on many excessively dry soils and to a great depth—up to 8 m. (under forest at the Dzhanybek Field Station in Kazakhstan). They have been used by the Dzhanybek Agricultural Meteorological Station for the past three years.

The author wishes to thank I. A. Tumanov, a worker at the Dzhanybek Field Station, who helped in the making and testing of the auger.

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Chronicle

FIRST DELEGATES' CONVENTION OF SOIL SCIENTISTS OF THE USSR

S. A. Shuvalov

FROM May 12th to 18th the first delegates' convention of USSR soil scientists convened in Moscow. The convention summoned by the Organization Committee of the All-Union Society of Soil Scientists was attended by 242 delegates elected on the basis of representation, one delegate to ten members of the Society. Besides the delegates, there were over 700 participants invited from schools of higher education, scientific-research, industrial and other organizations. Foreign guests also participated in the work of the convention: Professors Shen Dzhi-pey and U-Dzhikhua from China, Ewald and Kasch from the German Democratic Republic, de Gleria from Hungary, I. I. Tomaszewski and B. S. Dobrzanski from Poland, Kosil from Czechoslovakia, N. Pavichevich and G. Filippovsky from Yugoslavia, Academicians I. F. Stranskiy from Bulgaria and Kosil from Czechoslovakia, and corresponding member of the Academy of Sciences, N. Chernesku, from Rumania.

The work of the convention proceeded strictly according to the program approved by the Bureau of the Division of Biological Sciences, Academy of Sciences, USSR.

The convention opened with a word of introduction by Academician V. N. Sukachev.

Welcome addresses and letters were heard from Academician A. N. Nesmeyanov, president of the Academy of Sciences, USSR, from the presidium of the V. I. Lenin, All-Union Academy of Agricultural Sciences, from the Ministry of Agriculture, USSR, from a number of foreign scientific organizations, schools and soil scientists' societies, and others.

Academician I. V. Tyurin delivered a lecture on "The immediate and urgent tasks of USSR soil scientists," outlining the scope of the convention.

In the plenary sessions, May 13th, the following reports prepared by teams of authors were heard on basic problems of soil science.

1. N. N. Rozov: The condition and development of the soil classification problem.
2. P. A. Letunov: The division into soil-geographical regions.
3. S. S. Sobolev and M. N. Malyshkin: Qualitative appraisal of soil and land resources.
4. A. V. Sokolov: Soil factors in fertilizer effectiveness.
5. S. S. Sobolev: Control of soil erosion in the USSR.

The work of the five sections of the convention was performed during May 14, 15, and 16.

A total of 221 reports by Soviet soil scientists and 11 by foreign scientists were heard during the section meetings.

The subject of the reports primarily concerned discussion of the foregoing basic problems, demonstrating, however, a great multiplicity of aspects in all the sections. Thus, the session reports actually represented surveys of the scientific and practical work of Society members in all branches of soil science.

Thirty-eight reports were heard in the section on soil genesis and classification. They concerned problems of biological and geological rotations of substances; rates, dynamics and energetics of soil-formation processes; composition and methods of studying clay minerals and the establishnent of a general and regional classification of soils.

Foreign scientists discussed the problems of soil genesis and soil classification in Poland (B. S. Dobrzanski), Rumania (N. Chernesku), and Yugoslavia (N. Pavichevich), S. V. Zonn and Li Chen-Kvey lectured on soils of China's tropical zone.

Thirty-one lectures were heard on these subjects: the division of soil regions for agricultural purposes, the principles and methods of qualitative evaluation (site-index) of soils and land resources, and large-scale soil mapping.

Prof. V. Kosil discussed "Comprehensive soil investigation and its application to the solution of scientific and practical problems of agricultural production." Professor Kasch spoke on "Soil site index in the German Democratic Republic."

In the section on soil fertility 56 reports were given on various subjects: humus and biological soil problems, nitrogen, phosphorus, potassium and soil microelements, liming and soil acidity, and general problems of soil fertility. Professor li Gleria reported on the physico-chemical and colloid processes occurring in soils. Prof. N. I. Tomaszewski delivered two reports: on the transformation processes of organic matters in soils, and on the fertility of soils in Poland.

Thirty-seven reports were heard in the section on soil physics. Problems of water, air and heat conditions in soils, soil structure and physico-mechanical properties, and soil tillage and methods of investigation were discussed.

The foreign guests delivered the following reports: Professor Shen-Dzhi-pey—The influence of drying in rice soils on their fertility and yield; Academician Novak—The method of determining the aggregate size distribution in soils; Professor Ewald—Investigation results on the dynamics of forest soil moisture in Eberswald region.

In the section on amelioration, subsection soil erosion, 67 reports were heard on problems of meliorative division into districts, amelioration of swamped, salted, and solonetzic soils, on general and zonal problems of erosion control, and on problems of methods.

The concluding plenary sessions of May 17 were devoted to the Society's organization problems and to the adoption of resolutions.

The convention listened to Professor S. V. Zonn's progress report on the activity of the Organization Committee of the All-Union Society of Soil Scientists.

In March of 1956 the Bureau of the Division of Biological Sciences–Academy of Sciences–USSR, had resolved to continue the Society's activity; an Organization Committee was set up, headed by Academician I. V. Tyurin. This Committee has performed an important work in uniting the soil scientists of the USSR.

The Society admitted 2450 members, which are united locally in 15 branches and 30 divisions. The membership is composed of 932 members from institutions of scientific research, 822 from the schools of higher learning, 683 from the Ministry of Agriculture and industrial organizations, and 13 who are pensioners. Moreover, 16 institutions have collective memberships in the Society.

Seven permanent commissions and two subcommissions were formed around the Society's Organization Committee, which will direct work within the principal divisions of soil science.

The Organization Committee has established relations with the International Society of Soil Scientists; 36 Soviet soil scientists attended the Sixth International Congress of Soil Scientists in Paris. Soviet soil scientists also participate in the work of the permanent commission of the International Society of Soil Scientists; I. V. Tyurin and corresponding member of the USSR Academy of Sciences, V. A. Kovda, were elected into the executive body of the International Society of Soil Scientists.

The convention unanimously approved the work of the Organization Committee and discussed and accepted the Statutes of the All-Union Society of Soil Scientists prepared by the Organization Committee. The elections were then held and resolutions adopted.

Honorary members elected to the All-Union Society of Soil Scientists were: V. N. Sukachev, N. A. Dimo, A. I. Bezsonov, A. N. Sokolovsky, Z. Yu. Shokal'skaya, S. K. Chayanov, F. V. Chirikov, and the foreign soil scientists V. Novak, G. Orr, I. I. Tomaszewski, I. F. Stransky.

Fifty members and 6 candidates were elected into the membership of the central council of the All-Union Society of Soil Scientists. The Presidium of the Central Council, composed of 15 members, was elected in the first session of the Central Council, which met following the convention. The final membership of the Central Council is as follows:

Central Council Presidium

I. V. Tyurin	president
V. A. Kovda	vice-president
A. V. Sokolov	“ “
K. P. Gorshenin	“ “
S. V. Zonn	“ “
I. S. Lupinovich	presidium member
O. K. Kedrov-Zikhman	“ “
A. A. Rode	“ “
I. N. Antipov-Karatayev	“ “
M. S. Gilyarov	“ “
Ye. N. Ivanova	“ “
A. N. Rozanov	“ “
N. S. Avdonin	“ “
N. I. Gorbunov	“ “
S. A. Shuvalov	responsible secretary

Central Council Members

I. P. Gerasimov, N. A. Kachinskiy, M. M. Kononova, Ya. V. Peive, P. A. Vlasyuk, A. A. Zavalishin, N. N. Rozov, S. S. Sobolev, I. I. Sinyagin, Ye. N. Mishustin, V. R. Volobuyev, G. S. Davtyan, M. N. Sabashvili, U. U. Uspanov, S. N. Ryzhov, F. Ya. Gavrilyuk, N. L. Blagovidov, V. G. Roukis, Ye. V. Rubilin, A. M. Grinchenko, G. N. Sambur, O. G. Khallik, P. G. Aderikhin, B. A. Kalachev, T. I. Yevdokimova, A. A. Yerokhina, P. A. Letunov, M. N. Pershina, N. I. Skrynnikova, M. N. Malyshkin, S. N. Taychinov, K. A. Krumin'sh, A. V. Peterburgskiy, N. P. Remezov, D. G. Vilenskiy.

Central Council Candidates

V. M. Fridland, N. A. Nogina, V. N. Simakov, I. G. Dikusar, V. G. Zol'nikov, S. A. Kolyago.

Inspection Commission Staff

N. P. Bulgakov, I. P. Serdobol'skiy, A. S. Fat'yanov, P. A. Petrov, M. K. Daraseliya, Ye. S. Blazhniy, V. A. Nosin, N. B. Vernander, N. I. P'yavchenko, V. N. Zavaritzkiy, D. M. Guseynov.

In this manner the All-Union Society of Soil Scientists received the proper organizational structure to establish it as one of the larger USSR scientific societies.

Mention was made, in the resolutions adopted by the convention, of the important work accomplished by Soviet soil scientists during the past years drawing the Government Soil Map, medium-scale soil maps of various republics, territories and districts, and large-scale soil maps of collective and state farms.

Recently, much attention is being directed to the division of agricultural soil districts, and toward a solution of the major problem of site quality index. Important investigations are being carried out in the fields of soil physics, chemistry and biology, and in the utilization of fertilizers. Permanent investigations on the dynamics and rates of soil processes are expanding. Through new methods of investigation such as the application of radioactive and stable isotopes, new ideas on the availability of soil phosphates, nitrogen absorption of plants, soil acidity, the nature of organic-mineral colloids and iron-organic compounds, and other problems of soil science have been solved.

Nevertheless, as noted in the resolutions of the convention, the studies are still insufficiently advanced in a number of fields. The infiltration of scientific achievements in soil science into the field of agricultural production remains unsatisfactory, largely because of insufficient training of soil scientists and agricultural chemists, and because of the lack of an efficiently organized system for efficient use of this personnel. In particular, the long pending problem of organizing a scientific-industrial Service of Soil Science and Agricultural Chemistry has not yet received a solution.

In its resolutions the convention defined the soil scientists' immediate tasks as they had been formulated by the Twentieth Congress of the Communist Party of the Soviet Union in the resolution of the February Plenary Session of the CPSU Central Committee and of the session of the Supreme Soviet of the USSR regarding further development of the collective farm system. In particular, the convention directed the soil scientists' attention toward the need for further studies of agricultural soil division into districts, and for medium and large-scale mapping, and theoretical and practical site quality index to to establish a scientific basis for efficient utilization and increased productivity of lands in various natural zones and provinces of the USSR.

The development of a single classification system of soil groups and subgroups and fundamental principles defining the other subdivisions was considered among the immediate tasks; it will proceed from the basic principles adopted by the Interdepartmental Commission on Classification, Systematics and Soil Nomenclature.

The convention recommended that soil scientists and agricultural chemists perform their permanent (key) investigations jointly with the other agricultural specialists to develop a complete set of measures aimed at an effective utilization of the soil surface. One of the basic parts of this project is the development of fertilization procedures applicable to local conditions and crop rotations.

Studies on soil genesis, as a natural body and principal means of production are to be expanded and intensified. In this connection still more intensive regional soil investigations are needed on heat, water, gases and salt conditions, alterations in the composition of the organic part of soils and in the combination of microorganisms and soil fauna, metabolic exchanges in the soil-plant-atmosphere system, and the energy aspect of such exchanges and the soil formation process. The studies of swampy, salted and eroded soils are also to be intensified, in order to work out efficient methods of amelioration.

As an assignment for the newly elected Central Council the convention specified a series of urgent problems which will necessitate the mobilization of the Society's resources and require the attention of appropriate organizations. These problems are: improvement in the training of specialists in soil science and agricultural chemistry and qualitative improvement in the training of agronomists in soil science and agricultural chemistry; a speedy establishment of a service of soil- and agricultural chemistry; organization of soil science institutes within the Siberian Division of the USSR Academy of Sciences, and in the branches of the USSR Academy of Sciences; publication of a periodical of the Society, of a scientific journal of agricultural chemistry, and a review journal on soil science and agricultural chemistry; edition and publication of separate monographs and textbooks for the principal departments of soil science, and of an adequate dictionary of soil science and agricultural chemistry, and publication of translated works; publication of the collected works of A. G. Doyarenko; and manufacture of indispensable and accessible apparatus for soil and agricultural-chemical research.

The convention expressed the need for the organization of meetings on various scientific and practical problems, not only in Moscow, but in other important cities of the Russian Republic and in other Union republics.

The convention instructed the Central Council of the Society to strengthen the ties with the foreign societies of soil scientists and with the International Society of Soil Scientists, and to contribute to the exchange of scientific publications.

The Delegates' Convention of the All-Union Society of Soil Scientists assured that Soviet soil scientists and agricultural chemists will honorably fulfill the tasks assigned to them, and will thus earn the right to appear in the front rows of the builders of Communism in our country.

After the convention, a soil expedition was undertaken to Moscow-Tula-Orel-Kursk. Convention members examined podzol, grey forest and chernozem soils, and results of permanent studies. The demonstration of soil profiles and and communications on results of investigations —of the podzol soils of Podushkinsk forestry by I. N. Skrynnikova, of the grey forest soils in the Pakhomovo state farm territory by A. I. Troitzkiy, and of the Streletzk steppe chernozems by Ye. A. Afanas'eva—were heard with great interest, and stimulated a lively exchange of views.

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